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Proceedings of the Eleventh Advanced Communications Technology Satellite Propagation Studies Workshop (APSW XI)

Held in Oklahoma City, Oklahoma October, 22–23, 1998

Nasser Golshan
Editor

Christian Ho
Co-Editor

December 10, 1998

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
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ABSTRACT

The Advanced Communications Technology Satellite Propagation Studies Workshop (APSW) is convened each year to present the results of the Advanced Communications Technology Satellite (ACTS) Ka-band propagation campaign. Representatives from the space community including industry, academia, and government who are interested in radiowave propagation at Ka-band are invited to APSW for discussions and exchange of information. The ACTS Propagation campaign will complete five years of Ka-Band data collection at seven sites in North America by December 31, 1998. Through this effort, NASA is making a major contribution to the effective utilization of this band by providing timely propagation data and models for predicting the performance of Ka-band links between space and ground.

PREFACE

The ACTS Propagation campaign will complete the planned five years of Ka-band data collection at seven sites by December 31, 1998. Through this effort, NASA is making a major contribution to the effective utilization of this band by providing timely propagation data and models for predicting the performance of Ka-band links between space and ground. The Eleventh ACTS Propagation Studies Workshop (APSW XI) was held in Oklahoma City, OK, at the Embassy Suites. This set of proceedings contains the presentations from that workshop.

This year the ACTS workshop focused on four areas:

1) Latest results and findings from ACTS propagation experimenters.
2) Theoretical and empirical considerations for propagation prediction models including interaction of precipitation with the antenna for design of satellite systems at Ka band.
3) Plans for dissemination of the findings of the ACTS Propagation Campaign.
4) Consideration of NASA's ACTS blue ribbon panel findings regarding the ACTS propagation campaign.

Session 1, Spacecraft and Program Updates, chaired by R. Acosta, provided an overview of ACTS spacecraft and program status as well as an update on NASA propagation studies by N. Golshan.

Session 2, Status Reports, chaired by L. Ippolito, provided status reports from ACTS propagation experimenters at seven Ka-band measurement sites, a summary of attenuation observations for all seven sites, and a status report from the ACTS Propagation Data Center.

Session 3, Special Topics, chaired by J. Goldhirsh, included reports on propagation effects modeling and revision of NASA's propagation handbooks.

Session 4, Propagation Campaign With ACTS in Inclined Orbit, chaired by R. Acosta, included a report by R. Bauer on the findings of NASA's ACTS Blue Ribbon Panel regarding propagation experiments during ACTS inclined orbit, and a report by D. Westenhaver on propagation terminals tracking ACTS in inclined orbits. Session 5, Plenary, was chaired by R. Crane and D. Rogers.

The success of the meeting owes a lot to the speakers and session chairs and the active participation of all attendees. We would like to express our thanks to Ms. M. Wilkins of JPL and to Ms. C. Jones of the University of Oklahoma for meticulously caring for many administrative details of the meetings. Last but not least, we would like to thank Roger Carlson of the JPL technical information section for coordinating the publication of this document.

The next ACTS Propagation Studies Workshop will take place in conjunction with NASA Propagation Experimenters (NAPEX) Meeting in the greater Washington DC area in early June 1999; the exact date and location will be announced by January 1999.

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SESSION 1. SPACECRAFT & PROGRAM UPDATES

Chair: R. Acosta

(NASA/LeRC)

Spacecraft and ACTS Program Updates

R. Acosta

NASA/LeRC

APSW XI

October 22-23, 1998

Oklahoma City, OK 73108

hnology Satellite
munications Tec
Advanced Com
ACTS
NASA Lewis Research Center
Cleveland, Ohio

ADVANCED COMMUNICATIONS TECHNOLOGY SATELLITE (ACTS)

- Original goal to maintain US pre-emminence in communications satellite technology
- Experiments began December 6, 1993.
- Initial 2 year mission extended (4 yr. design life) - sixth year now underway!
- Over 150 organizations involved in 92 experiments; 81 demonstrations to various audiences.

Launched September 12, 1993 aboard STS 51 - Discovery.

Lewis Research Center
Cleveland, OH

KEY ACTS TECHNOLOGIES

High Gain, Fast Hopping Spot Beams

- EIRP >64 dB
- G/T >20 dB/K
- Frequency Reuse >> 4

Onboard Processing & Switching

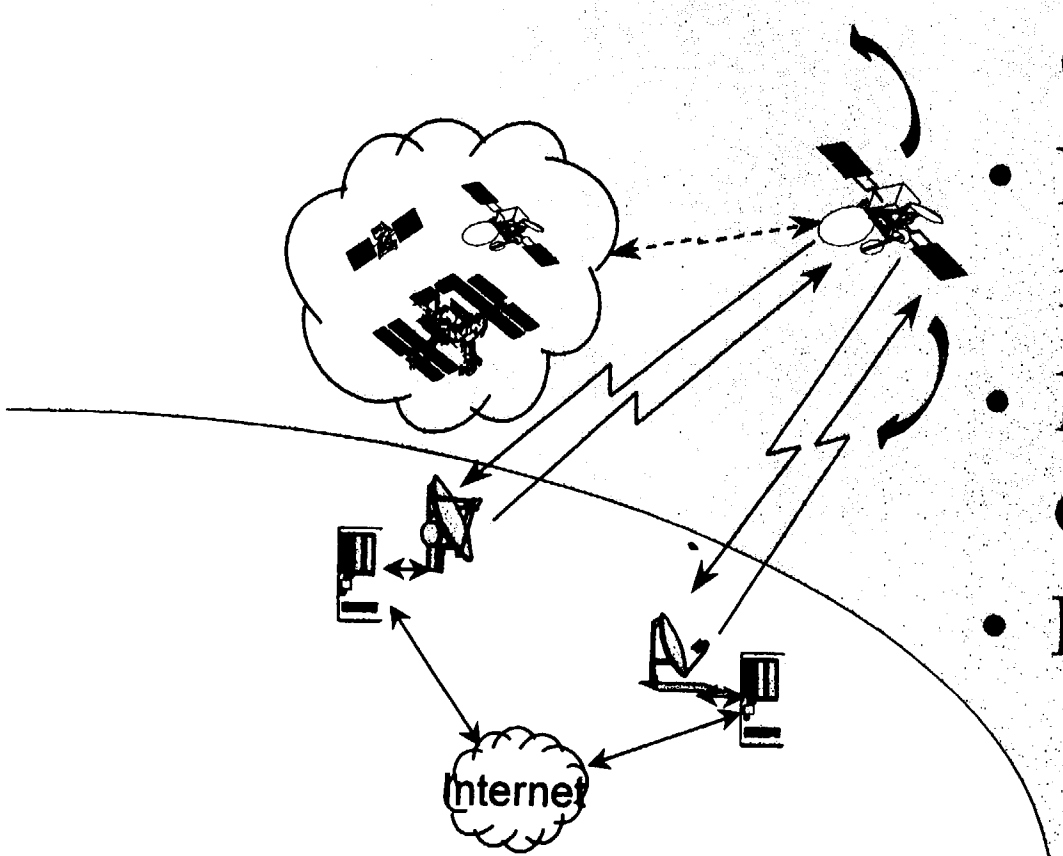
- Baseband Switching at 64 kbps circuit level
  - Max throughput of 220 Mbps
  - Full mesh, single hop connectivity
- Wideband Switch Matrix of 3 channels at 900 MHz each

Ka-Band

- 30/20 GHz RF spacecraft & earth station components
- Adaptive rain fade compensation
  - Propagation measurements to characterize band
  - Only currently available 30/20 GHz satellite testbed in U.S.

Lewis Research Center
Cleveland, OH

EXPERIMENT AREAS



- Transition to commercial assets
- Networking and interoperability
- Inclined orbit operations
- Ka-band technology

NASA PROPAGATION STUDIES
STATUS

Nasser Golshan

Jet Propulsion Laboratory
California Institute of Technology

CURRENT FOCUS: ACTS PROPAGATION CAMPAIGN

OBJECTIVE OF ACTS PROPAGATION CAMPAIGN:

- To leverage NASA's Advanced Communications Technology Satellite (ACTS) to characterize radiowave propagation at Ka-band for utilization by U.S. industry and the space community

EXPECTED RESULTS & OUTPUTS OF THE ACTS PROPAGATION CAMPAIGN:

- Ka-band propagation data
- Prediction models of rain and atmospheric attenuation and scintillation
- Fade and nonfade distributions
- Frequency scaling models
- Diversity models
- Mitigation schemes for signal impairments due to propagation
- Wet antenna effect model
- Rain climate region map revision
- Revised propagation handbooks for design of satellite communications systems
- Contributions to regulatory organizations

ACTS PROPAGATION CAMPAIGN MILESTONES

MILESTONE	CALENDER YEAR
• First planning workshop held in Santa Monica, Ca	1987
• Announcement of Opportunity released	1989
• Virginia Polytechnic Institute commissioned to develop the ACTS Propagation Terminal	1989
• Terminals delivered and ACTS launched	1993
• Two years (14 station-years) of ACTS propagation data distributed on CD-ROM	1996
• Work started to use ACTS propagation data to revise propagation models and handbooks	1996
• Three years (20 station-years) of ACTS propagation data distributed on CD-ROM	1997
• Revised propagation models and handbooks to be distributed	1998
• Four years (27 station-years) of ACTS propagation data to be distributed on CD-ROM	1998
• Contributions to regulatory organizations to be made	1998-1999
• Five years (34 station-years) of ACTS propagation data to be distributed on CD-ROM	1999
• ACTS transitions into inclined orbit	1999

NEW FOCUS FOR NASA PROPAGATION STUDIES

- Source of Funding for NASA Propagation Studies: NASA's Cross Cutting Technology UPN 632-50
  - Entire 632 program managed through a GSFC Formulator (Gary Martin) and a JPL Implementor (Steve Prusha), with high level HQ oversight by Code SM
  - NASA Enterprises are the main customers for NASA's Cross Cutting Technology
  - 632 program segregated into major "Thrust Areas"
  - Communications is part of "High Rate Knowledge Delivery" Thrust Area with manager at LeRC (TBD)
  - JPL Propagation Studies is part of Communications
- JPL Propagation Studies will focus on priorities of "High Rate Knowledge Delivery" as they are defined.

SESSION 2. EXPERIMENTS STATUS REPORTS

Chair: L. Ippolito

(Stanford Telecom)

MODEL COMPARISON AND VERIFICATION FOR SCINTILLATION, FADE DURATION, AND CLOUD EFFECTS

BRADLEY E. JAEGER, DONALD L. HOPKINS, DAE HONG KIM, AND CHARLES E. MAYER

I. Scintillations

Scintillation model predictions were compared to four years of the Fairbanks ACTS data at 20.2 and 27.5 GHz. Models used in the comparison are Karasawa et al. [1], ITU-R [2], Ortgies-N [3], Ortgies-T [3], DPSP (Direct Physical Statistical Prediction) [3], MPSP (Modeled Physical Statistical Prediction) [3], and Tervonen et al. [4]. Dependencies of these seven models are shown in Table 1. The monthly average for scintillation standard deviation, along with all the model predictions using the local meteorological parameter input, is plotted in Figs. 1 and 2 for 20.2 and 27.5 GHz respectively.

TABLE 1. SCINTILLATION MODEL COMPARISON

Scintillation Model	Year	freq. dep.	sin θ dep.	Par.	H (m)	Data source	Regression	Model Restrictions	Fade/ Enhan.
Karasawa, Yamada, Allnutt	1988	0.45	-1.3	N_{wet}	2000	Yamaguchi, Japan (11.45 GHz, 4,6.5,9°)	m vs. N_{wet}	7 - 14 GHz $4 < \theta < 30°$	Regres. m vs. variance
ITU - R	1990	0.583 (7/12)	-1.2	N_{wet}	1000			6 - 20 GHz $4 < \theta < 30°$	Regres.
Ortgies-N	1993	0.605	-1.2	N_{wet}	1000	Darmstadt, Ger. (Oly)	$\ln(\sigma_x^2)$ vs. N_{wet}	$6.5 < \theta < 30°$	∫ Gauss. (sym.)
Ortgies-T	1993	0.605	-1.2	T	1000	Darmstadt, Ger. (Oly)	$\ln(\sigma_x^2)$ vs. T	$6.5 < \theta < 30°$	∫ Gauss. (sym.)
DPSP-Direct Physical Statistical Prediction	1997	0.583	-1.2	T	2058 + 94.5 T	Louvain-la-Neuve, Bel. (12.5, 29.7) and Milan, Italy (19.8)	Ver. Refrac. gradient (radiosonde) to give $\ln(\sigma_x^2)$ vs. T	T > -5 C	∫ Gauss. (sym.)
MPSP-Modeled Physical Statistical Prediction	1997	0.583	-.917	T	2058 + 94.5 T	Louvain-la-Neuve, Bel. (12.5, 29.7) and Milan, Italy (19.8)	Ver. Refrac. gradient (radiosonde) to give $\ln(\sigma_x^2)$ vs. T	T > -5 C	∫ Gauss. (sym.)
Tervonen, van de Kamp, Salonen	1998	0.45	-1.3	N_{wet}, P(Cu)	2000	Kirkkonummi, Finland (19.8, 29.7)	σ_x vs. N_{wet} & P(Cu)		

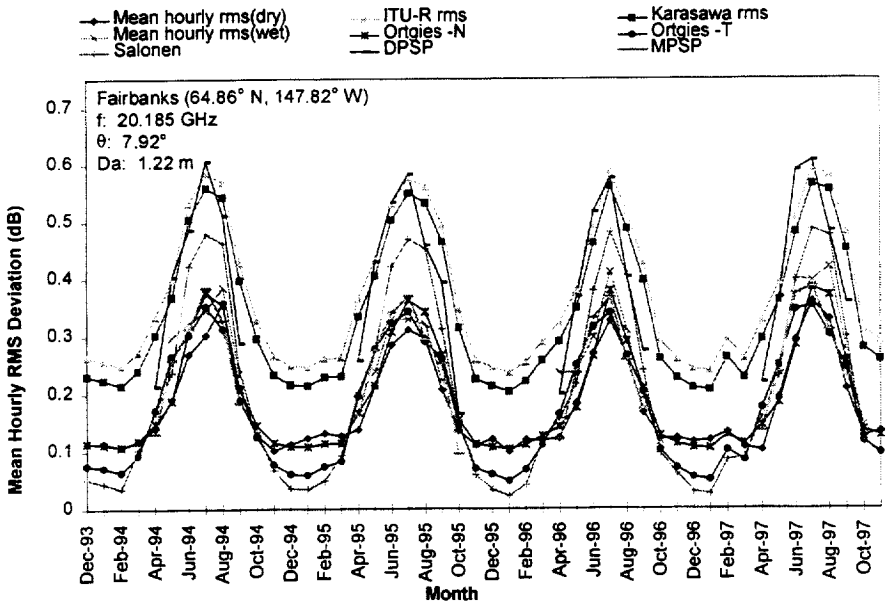


Fig. 1. 4 Year Comparison of Monthly Average 20 GHz RMS Deviation With Model Predictions

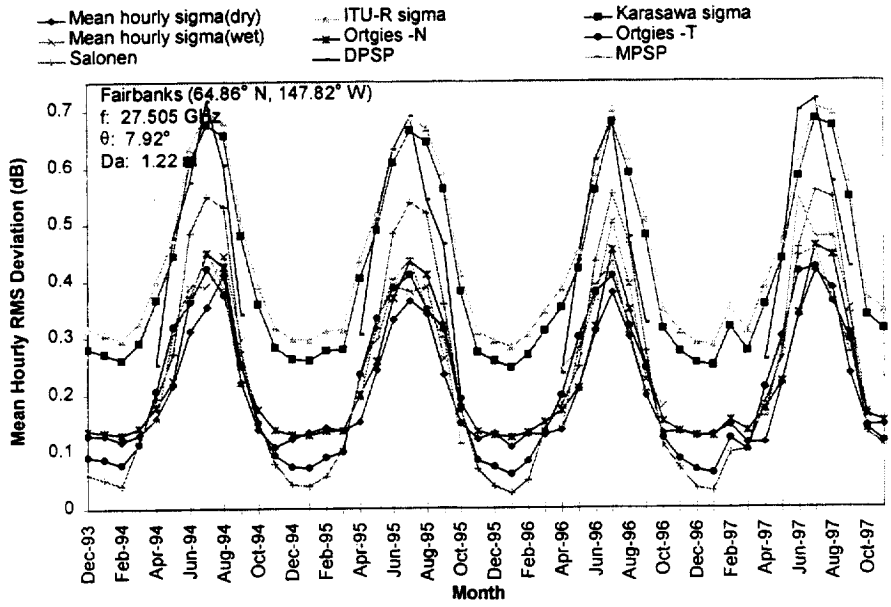


Fig. 2. 4 Year Comparison of Monthly Average 27 GHz RMS Deviation With Model Predictions

II. Matricciani Fade Model

Table 2 indicates the place of the Matricciani fade model among other models of fade durations. The data used in the development of each model are listed along with the basic modeling technique. The Matricciani model is not an engineering model since it requires the user to have a rain rate time series but it may provide better prediction accuracy than other models. It is mostly a mathematical construction with only storm translation speed, v, obtained from radar measurements in northern Italy. Compared to other fade duration models it also has the advantage of being able to predict fade times. At present, the only other model to do this is the Paraboni and Riva model.

TABLE 2. FADE DURATION MODEL COMPARISON

Model	Data Frequency	Data Location	Model Type	Engineering Model	Accounts for short fades	Predicts Fade Time
Matricciani [6], [7]		Po River Valley	Simulation with Synthetic Storm Technique	No	No	Yes
Paraboni & Riva [10]	11.6 GHz ITU Database	Fucino, Gera Lario, Spino d'Adda	Log-normal Long Durations Power-Law Short Durations	Yes	Yes	Yes
ACTS Rain Prediction Model [11], [12]	NA	NA	Log-normal Attenuation Spatial Correlation of Rain Cells Probability of Rain on the Path 2-dimensional Markov Process.	Yes	Yes (Rain)	No
Maseng & Bakken [13]	NA	NA	Log-normal Attenuation. 1-dimensional Markov Process	No	Yes (Rain)	No

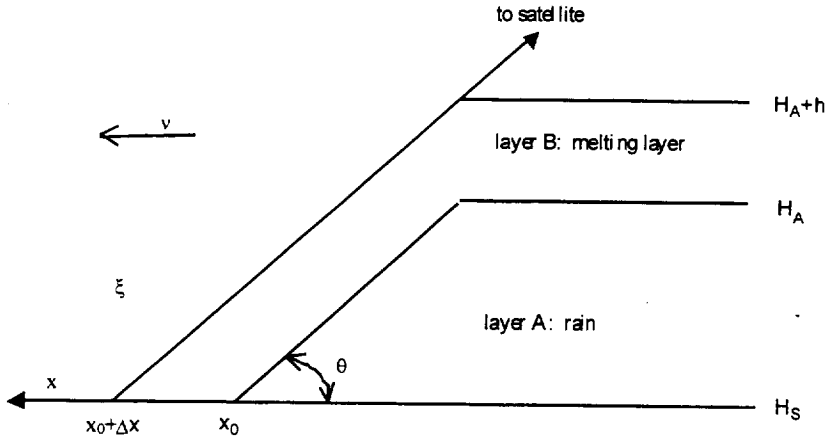


Fig. 3 Matricciani Rain Cell

Fig. 3 shows the precipitation pattern used in the Matricciani fade model. The cell is rectangular with a layer of rain at 20° C and a melting layer at 0° C. The variation in attenuation with time is simulated by the convolution of a function of rectangular shape with specific attenuation from a rain rate time series. In the Matricciani model, this convolution is done using a product in the frequency domain.

$$\check{S}_A(f) = \check{S}_{Y,A}(f) \cdot L_A \cdot \sin c(f \cdot L_A / v(\theta)) \cdot \exp(-j \cdot 2 \cdot \pi \cdot f \cdot \Delta x_0 / v(\theta))$$
$$+ r^{\alpha_B} \cdot \check{S}_{Y,B}(f) \cdot \Delta L \cdot \sin c(f \cdot \Delta L / v(\theta)) \quad (1)$$

The sinc functions result from the rectangular cell and the exponential is a shift due to the difference in path lengths, Δx. There is an extra term $r^{\alpha B}$ to account for the extra attenuation due to the melting layer. The simulated attenuation time series is then the inverse Fourier transform of (1). Fade durations greater than 60 seconds were then calculated from this attenuation time series. Statistics were recorded for the number of fades and the fade time. Since the Matricciani model attempts to account for fades from rain only, the statistics from the model were compared to statistics from measured ACA. Errors were measured for percentage of fade time and percentage of fades. The error at a given percentage and attenuation threshold was taken as

$$\varepsilon \equiv \ln\left(\frac{FD_{ACA}}{FD_{Matricciani}}\right) \quad (2)$$

Table 3 gives a summary of these errors for four years of Fairbanks data.

TABLE 3. MATRICCIANI MODEL ERRORS (DECEMBER, 1993-NOVEMBER, 1997)

	Number of Fades				Fade Time			
	1 dB ACA	3 dB ACA	5 dB ACA	7 dB ACA	1 dB ACA	3 dB ACA	5 dB ACA	7 dB ACA
20 GHz avg	0.022558	-0.01084	0.019154	0.033059	0.014517	0.022338	0.028899	0.027749
20 GHz rms	0.071022	0.055106	0.087449	0.088875	0.062319	0.07034	0.082712	0.072792
27 GHz avg	0.037327	0.047002	0.031158	0.0655	0.014491	0.022303	0.022052	0.049574
27 GHz rms	0.143646	0.09891	0.075965	0.14493	0.12134	0.072475	0.077938	0.126067

The positive signs in front of errors in table 3 indicate that in all but one case the Matriccianni model underpredicts both the number of fades and the fade time. Fig. 4 and 5 show graphically how well the Matriccianni model predicts number of fades and fade time at 27.505 GHz for a representative year in Fairbanks, December 1996-November 1997.

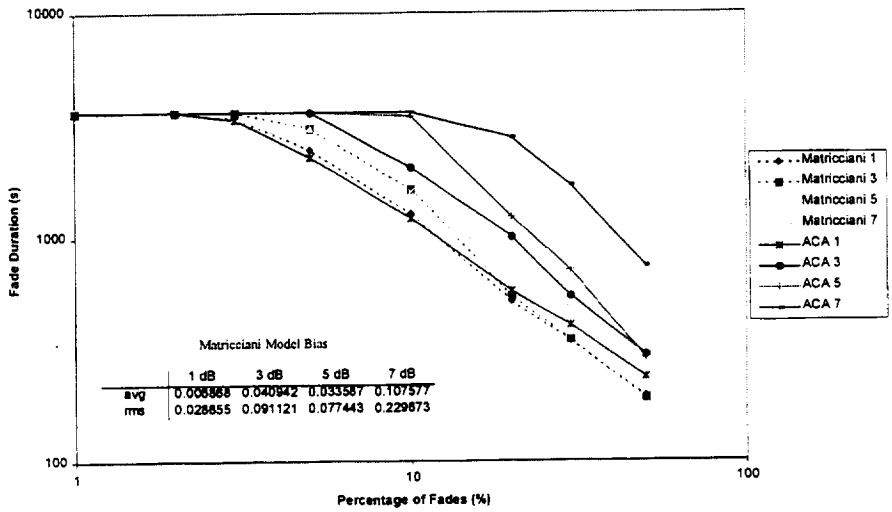


Fig. 4 - Number of 27 GHz ACA Fades Compared to the Matricciani Model.

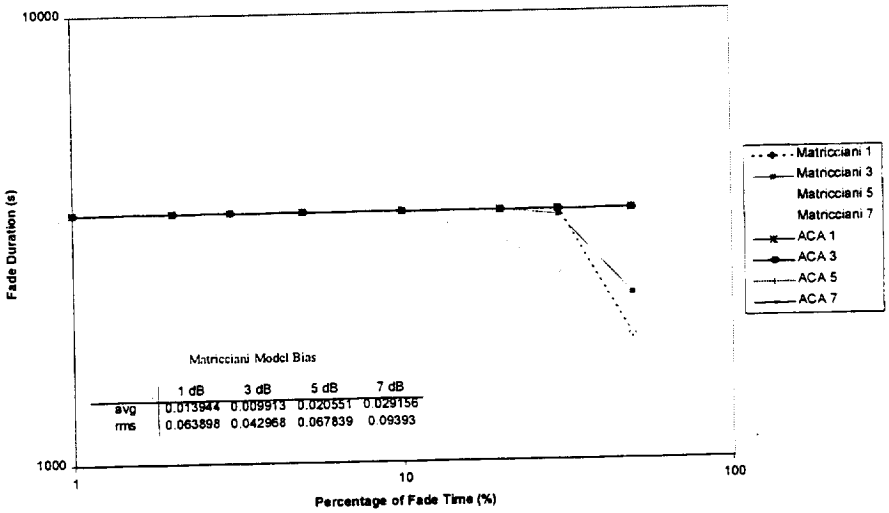


Fig. 5 - 27 GHz ACA Fade Time Compared to the Matriccianni Model.

Fig. 6 shows attenuation cumulative distribution function for the Matriccianni model compared to an ACA cdf at 27.505 GHz for a representative month at Fairbanks. The two dashed curves are model curves. There is one for optical gauge rain rate, ORR, and one for capacitive gauge rain rate, CRR. The ACA curves fall above the model curve for low attenuations. It may be that if the Matricciani model had a development accounting for antenna wetting this discrepancy would be resolved.

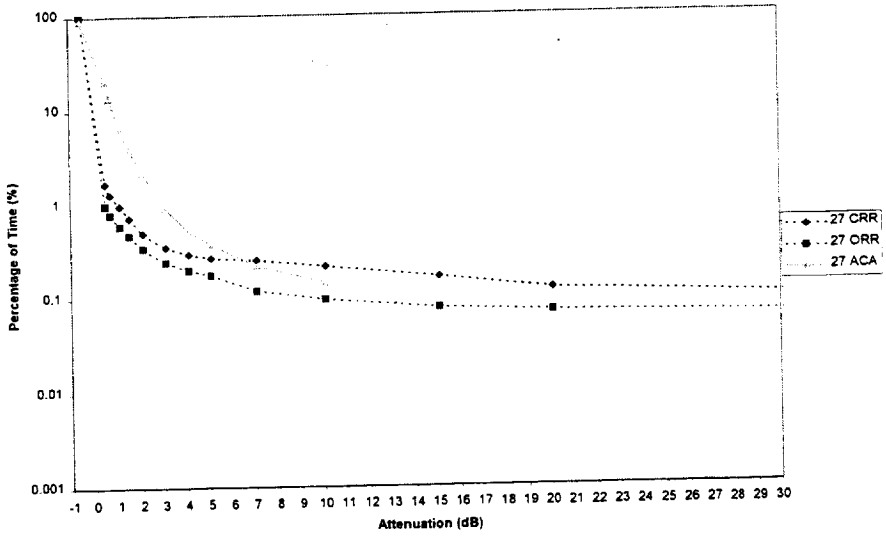


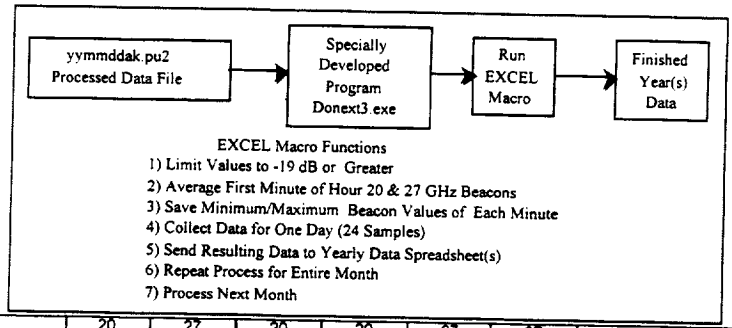
Fig. 6 - (June, 1997) 27.505 GHz ACA Compared to the Matricciani Model.

III. ACTS Data Correlated to Gaseous, Rain, and Cloud Attenuation Models

This section explores correlation of received ACTS beacon values to atmospheric attenuation by adapting National Climatological Data Center (NCDC) data used in clear sky (gaseous), rain, and cloud attenuation models. Attenuation due to clear sky and rain utilize ITU-R semi-empirical attenuation models, however cloud attenuation is more difficult to model due to highly variable cloud structures. Prior to July 1996, NCDC cloud cover data is recorded in tenths of total cover, with 10/10 = total cover. After June 96 NCDC recorded cloud data format changed, listing only five cloud cover increments: 0 (SKC or CLR), 1/8-1/4 (FEW), 3/8-1/2 (SCT), 5/8-7/8 (BKN), and 8/8 (OVC), and up to four distinct cloud ceilings. Cloud attenuation models are investigated, but require knowledge of the density of water (g/m^3) along the propagation path, which is generally not known. A SkyCam (modified digital camera) is used to help correlate viewed cloud conditions to NCDC published values. This section will show how recorded ACTS propagation data compares to the sum of attenuation from the three propagation models.

A. ACTS Data Collection Procedure

The first step in the analysis is to collect ACTS data in a form, which will allow comparisons over a long period. To accomplish this, a special program (Donext3.exe) was developed by Dave Westenhaver of Westenhaver Wizard Works to take preprocessed ACTS data and extract only the first minute of data (60 samples) from each hour selected. After this data is extracted, the next step is to limit the range of data to values greater than a threshold of –19 dB. This threshold is chosen since any values lower than this are considered below the noise floor of the equipment. After these erroneous values are eliminated, the remaining values for the minute are manipulated, where the average, maximum, and minimum values are saved for use in attenuation and scintillation studies. Finally the values (one per hour from hh:00:00 to hh:00:59) are collected and placed into a set of yearly ACTS averaged data for use in EXCEL. Averaging, saving maximum/minimum values, and compiling the data is done via an EXCEL macro specially developed for this purpose. Fig. 7 shows pictorially the data collection process and a sample of the collected data.



	20 Beacon Average	27 Beacon Average	20 Beacon Min	20 Beacon Max	27 Beacon Min	27 Beacon Max	20 Scintillation	27 Scintillation
1/1/97 0:00	-0.5	-0.7	-0.23	-0.51	-0.42	-0.74	0.28	0.32
1/1/97 1:00	-0.5	-0.66	-0.41	-0.77	-0.63	-0.95	0.36	0.32
1/1/97 2:00	-0.67	-0.98	-0.34	-0.69	-0.55	-0.98	0.35	0.43
1/1/97 3:00	-0.35	-0.49	-0.29	-0.61	-0.47	-0.87	0.32	0.4
1/1/97 4:00	-0.25	-0.42	-0.08	-0.48	-0.28	-0.69	0.4	0.41
1/1/97 5:00	-0.38	-0.53	-0.25	-0.57	-0.49	-0.74	0.32	0.25
1/1/97 6:00	-0.5	-0.68	-0.35	-0.69	-0.58	-0.82	0.34	0.24
1/1/97 7:00	-0.53	-0.76	-0.32	-0.59	-0.5	-0.81	0.27	0.31
1/1/97 8:00	-0.56	-0.73	-0.23	-0.65	-0.56	-0.93	0.42	0.37
1/1/97 9:00	-0.46	-0.62	-0.44	-0.82	-0.53	-0.99	0.38	0.46
1/1/97 10:00	-0.31	-0.45	-0.23	-0.67	-0.31	-0.81	0.44	0.5
1/1/97 11:00	-0.51	-0.57	-0.12	-0.56	-0.26	-0.71	0.44	0.45
1/1/97 12:00	-0.12	-0.53	-0.12	-0.71	-0.47	-1.03	0.59	0.56

Fig 7 - Conversion of Processed ACTS Beacon Data to EXCEL Data

B. Compiling NCDC Weather Data Used In The Analysis

Once the data is collected, the next step is to compile a set of weather data for the Fairbanks area. Required weather data used in the attenuation models includes: temperature (°C), relative humidity (%), rain rate (mm/hr), cloud cover (10^{ths}), and cloud ceiling (m). NCDC weather data is published monthly (with about a one-month delay) and is available to users from any local National Weather Service office in print form and is also available on a fee basis via the Internet. One exception to the fee based data requires an educational (.edu) address on the requester's internet server. Of course other sources of local weather data exist. For this analysis much of the data is collected from a CD published by NOAA and available at the UAF's Rasmussen library. A variety of weather data is available in hourly readings/summaries (including many of the required types) for years up to 1995. Data is recorded using local standard time and correlation to ACTS data requires an appropriate time shift. The only weather parameter required for the attenuation models not included is rain rate, however the total accumulation is included for the preceding hour in the data. In this analysis rain rate is estimated as (total accumulation for the hour)/(one-hour), giving an estimated rain rate for each sample period.

C. Modeling of Gaseous Attenuation

The first element of the analysis is to model the gaseous attenuation for the ACTS to Fairbanks slant path. The gaseous (clear-sky) attenuation model is by the CCIR (1990) in Report 719 [14], which is a semi-empirical model used to estimate the amount of gaseous attenuation. This model takes into account atmospheric gases attenuating effects due to oxygen and water vapor (not including water vapor in cloud structures). This commonly referenced attenuation model utilizes signal and weather data including:

f = Frequency (GHz)
T = Temperature (°C)
θ = Elevation angle (°)
ρ = Water Vapor Density (g/m^3)
RH = Relative Humidity (%)
Rain = yes/no (relates to scale height of ρ)

Calculations used in the gaseous attenuation analysis are included in Appendix B. Once the attenuation values are calculated, they are placed into a spreadsheet and correlated to the averaged ACTS beacon values. Fig. 8 shows the results of the comparison. Note the seasonal trends show nicely on the plots, but deep fades are not tracked since they are due to rain attenuation, studied next. Also note the correlation coefficients shown in the plots where the 20 GHz (89.1%) is better correlated than the 27 GHz (76.7%). This difference is mainly due to the higher variability of the 27 GHz signal.

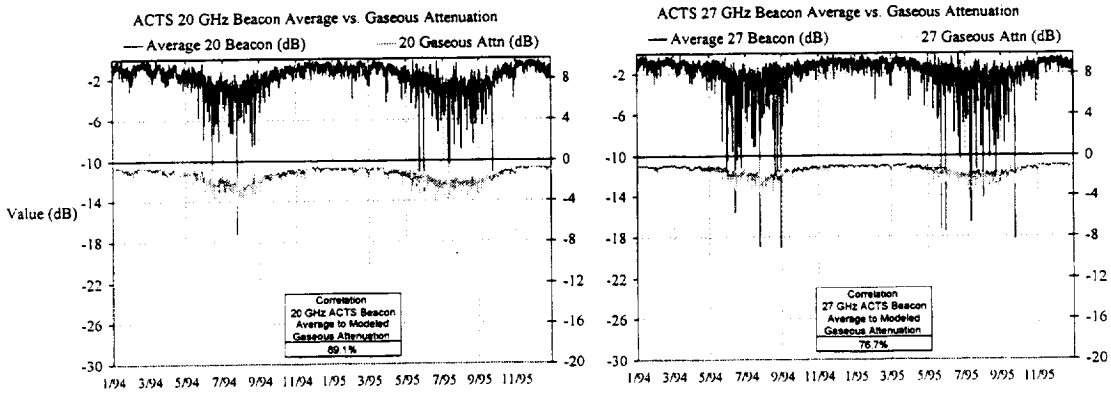


Fig 8 – Gaseous Attenuation vs. Averaged ACTS Beacon Values

D. Modeling of Rain Attenuation

Rain is the most severe attenuating factors in radiowave propagation, especially at higher frequencies. Even though this is the case, accurate measurement of rain rate (usually measured in mm/hr) during a rain event are not easily obtained. Errors exist from many sources including spatial diversity where the rain is falling in the propagation path, but not at the measurement site. Fig. 9 [15] shows sources of error for horizontal (L_H) and vertical (L_V). In addition most conductive rain cells have widely varying amounts of rain rates throughout the cell and the rain gauge is usually at one position. In this instance there are errors induced, since NCDC data is used as the source of rain rate data and the Fairbanks weather station is approximately 3 km from the ACTS terminal.

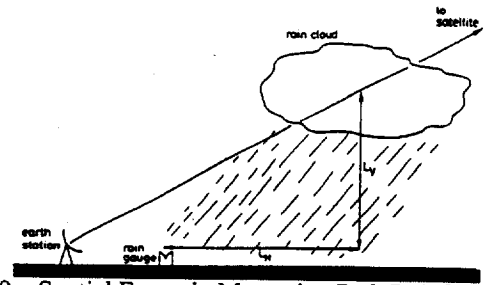


Fig 9 – Spatial Errors in Measuring Path Rainfall Rate

Now given a rain rate (approximated as total rain for the hour per hour) the only missing variable in the equation is the effective path length. For this approximation another piece of information is necessary, rain elevation within the cloud layer. Initially it was hoped that NCDC cloud ceiling represented the bottom of the rain, however published values did not seem to relate to the heights of rain-bearing clouds. Also values for cloud ceiling are not consistently available, so ITU recommendation RPN.618-4, 1996 gives a method to estimate the effective slant path length of the rain layer below the freezing height. Calculations required to estimate rain attenuation are shown in Appendix C, where only knowledge of station latitude is required to estimate the effective rain path [16].

One approximation made is there will be no rain, although there may be snow, for ground temperatures less than – 1°C. Liquid water in the form of rain is a strong attenuator of radio waves at ACTS frequencies, whereas snow mainly attributes to depolarization, which is not easily extracted from the ACTS data. NCDC data shows equivalent precipitation and does not differentiate this rain from snow. Luckily the transition of rain to snow occurs over a short period of the year in Fairbanks and should not skew the approximation significantly. Also to help account for the estimated rain rate experienced during the sampled period a value of 1.3 times the hourly rain accumulation from the NCDC data adjusts the hourly rate to a empirically defined rate (mm/hr) for the sample period. This 1.3 factor is determined from looking at the differences between the modeled gaseous + rain attenuation values, where the correlation of the two data sets is minimized for attenuation greater than 3 dB. Without more accurate radiosonde or real time rain rate data available, this approximation will certainly include errors, but the goal is to determine if NCDC data is usable to estimate rain attenuation with any degree of accuracy. Fig. 10 shows the results of the comparison, including modeled gaseous and rain attenuation.

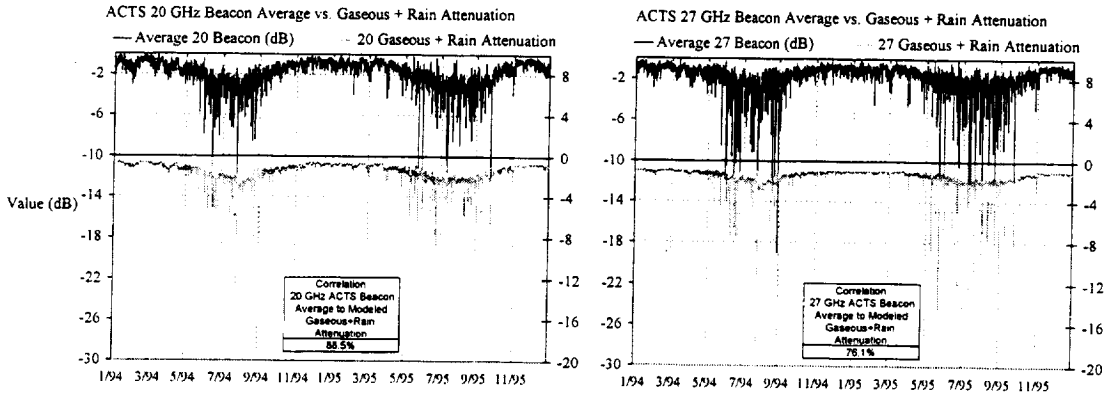


Fig 10 – Gaseous + Rain Attenuation vs. Averaged ACTS Beacon Values

It is interesting to note in Fig. 10 the deep fades, although not exactly correlated to the ACTS data, provide a better estimate of the actual performance of the satellite link based on the two models. One surprising result is the correlation of the two data sets did not improve with the added attenuating factor; in fact the correlation is slightly worse, 20 GHz from 89.1% to 88.9% and 27 GHz from 76.7% to 76.1%. This is probably due to an assumed "mismatch" of the estimated rain data and the ACTS beacon data. An analysis of the differences between the modeled attenuation and the actual ACTS data is performed using an absolute difference between the two values and calculating the differences in percent of total. This comparison is shown in Fig. 11. Note a difference of only 2 dB excludes all but 0.78% at 20 GHz and all but 1.81% at 27 GHz.

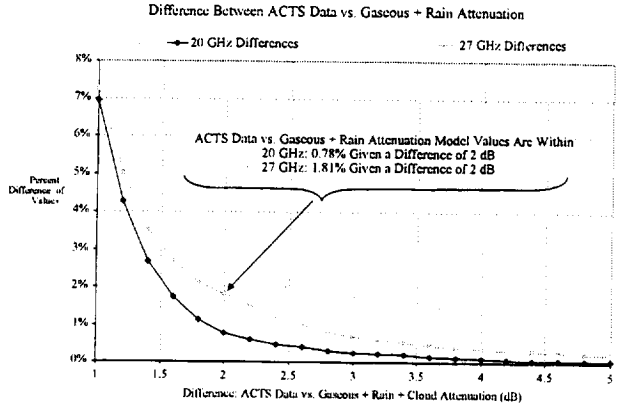


Fig 11 – Compare Gaseous + Rain Attenuation vs. Averaged ACTS Beacon Values

The overall trends in Fig. 10 show a slight discrepancy between the ACTS beacon values and the gaseous + rain attenuation models (like a dc offset) for the summer months, thus in the next section a cloud attenuation model is defined to help counteract this.

E. Modeling of Cloud Attenuation

The attenuating effects of clouds on a satellite link may not have as dramatic effect as the gaseous or rain attenuation, but clouds may be present for a significant amount of time in the propagation path. Rain on the other hand is usually limited to short-term duration events. Clouds contain a combination of suspended water droplets and if conditions allow ice crystals. The suspended water droplets change the dielectric properties of the propagation path and effect via absorption/scattering the propagating radiowave. To begin with an analysis of various types of clouds generally observed and their inherent properties is appropriate.

Haroules and Brown measured cloud attenuation in 1969 [17] at frequencies of 8, 15, 19, and 35 GHz also at frequencies of 15 and 35 GHz by Alshuler. Using these studies and others, water density of many cloud types has been estimated. Slobin [17] lists typical parameters of clouds in mid-latitude conditions. This approximation is not truly suited for Alaska conditions, however during the summer in Fairbanks many of the cloud structures present are similar to those described. The next element in any model are the equations necessary to predict cloud attenuation. E. Salonen and S. Uppala [18] formed a model to predict the specific attenuation of clouds for frequencies above 20 GHz. Their model is based on Liebe's MPM model [19]. The evaluation of this model uses the parameters shown in Appendix D.

Next Fig. 12 shows Slobin's results and lists 15 different cloud types at mid-latitudes, their specific water density (g/m^3), and typical heights above the ground (m) for top and bottom of each type of the 15 types of cloud structures. These 15 cloud types are grouped and adjusted such that the parameters for each cloud type (specific water density (g/m^3) and effective depth) when evaluated using the equations in Appendix D, represent attenuation values observed by correlating ACTS data and SkyCam views, discussed in the next section. Note in Fig. 12, effective path is only an estimate using estimated top and bottom as a guide.

Slobin's Cloud Types

Cloud Type	Density (g/m3)	Height Above Ground (m)	
		Bottom	Top
Heavy Fog 1	0.37	0	150
Heavy Fog 2	0.19	0	150
Moderate Fog 1	0.06	0	75
Moderate Fog 2	0.02	0	75
Cumulus	1.00	660	2700
Altostratus	0.41	2400	2900
Stratocumulus	0.55	660	1320
Nimbostratus	0.61	160	1000
Stratus	0.42	160	660
Stratus	0.29	330	1000
Stratus-stratocumulus	0.15	660	2000
Stratocumulus	0.30	160	660
Nimbostratus	0.65	660	2700
Cumulus-cumulus congestus	0.57	660	3400

New Cloud Models

Cloud Type	% Coverage	Density (g/m^3)	Height Above Ground (m)		Effective Path (m)
			Estimated Cloud Bottom	Estimated Cloud Top	
Stratus	0.8 - 1.0	0.18	245	830	440
Stratocumulus	0.6 - 0.79	0.15	555	1495	900
Nimbostratus	0.8 - 1.0	0.32	410	1850	500
Cumulus	0.2 - 0.59	0.35	660	3050	700
Altostratus	0.6 - 0.79	0.21	2400	2980	540

Fig 12 – Conversion of Slobin's 15 Cloud Types to New Model Cloud Types

Next the NCDC data is adapted to convert specific cloud coverage and ceiling data to these newly defined cloud types and then the calculations for cloud attenuation are performed. Fig. 13 shows a flowchart of how the clouds are classified and the parameters used in the model.

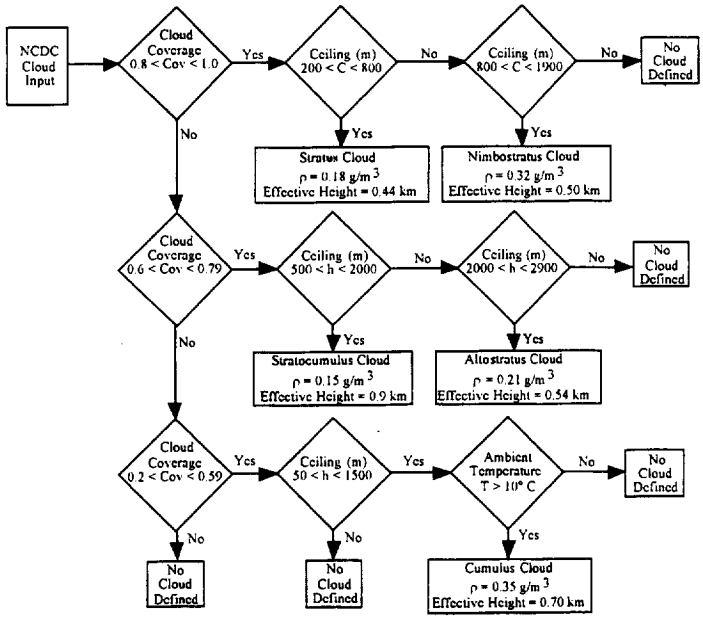


Fig 13 – Flowchart of NCDC Data to New Model Cloud Types

The next step is to calculate the attenuation due to clouds, then add this attenuation to gaseous and rain attenuation values, calculated earlier. Fig. 14 shows the results of this comparison. Note in this figure the dc offset noted earlier is not observed.

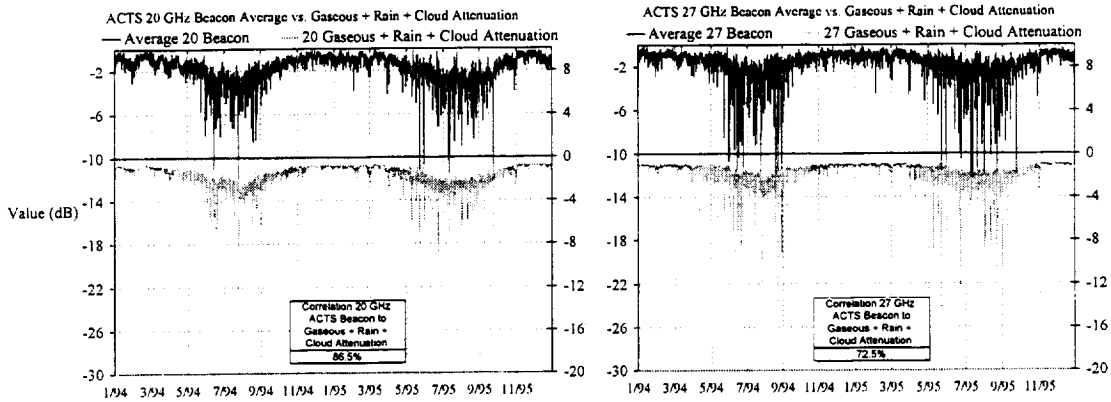


Fig 14 – Gaseous + Rain + Cloud Attenuation vs. Averaged ACTS Beacon Values

Again an analysis of the differences between the modeled attenuation and actual ACTS data is performed using an absolute difference between the two values and calculating the differences in percent of total. This comparison is shown in Fig. 15. Note a difference of only 2 dB excludes all but 0.62% at 20 GHz and all but 1.32% at 27 GHz, an improvement over the model with only gaseous and rain attenuation values. The final comparison is when smaller time frames (one day) of three-part attenuation is correlated with the ACTS data. This comparison is shown next.

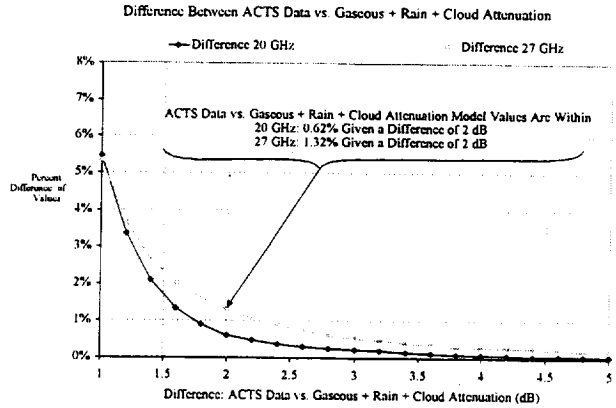


Fig 15 – Compare Gaseous + Rain Attenuation vs. Averaged ACTS Beacon Values

F. Comparison of One-Day Cloud Attenuation for Various Cloud Types

To ensure an accurate evaluation of cloud attenuation, a SkyCam is used to capture sky views and these views are used to coordinate cloud structures with observed ACTS attenuation. A sample of the SkyCam views and a schematic of the SkyCam apparatus are shown in Fig. 16.

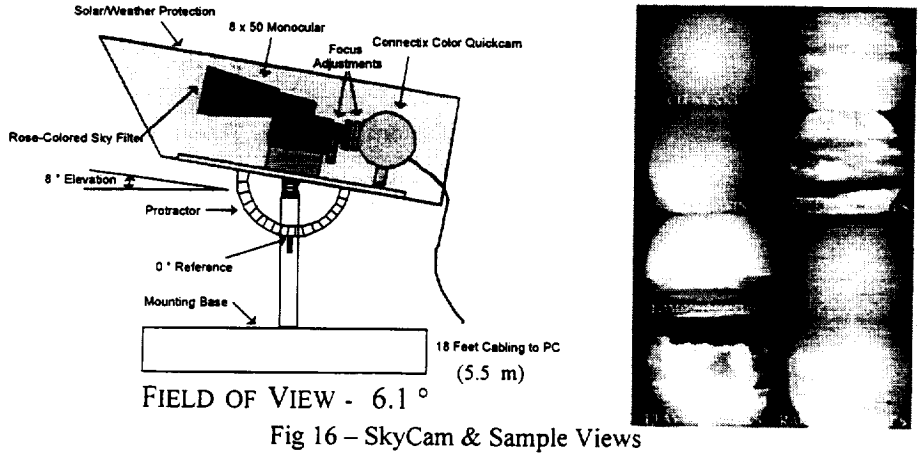


Fig 16 – SkyCam & Sample Views

The first type of cloud structure examined is that of cumulus clouds at/above cloud ceiling of 1500 meters. Fig. 17 shows the correlation of the ACTS beacons with the modeled attenuation. Also shown is the differences of the models with and without cloud attenuation and whether the models under or over predict the actual averaged ACTS attenuation. The curves on the right portion of the plot are when rain occurred in the signal path; otherwise where the cloud is noted the modeled attenuation tracks well with the actual data.

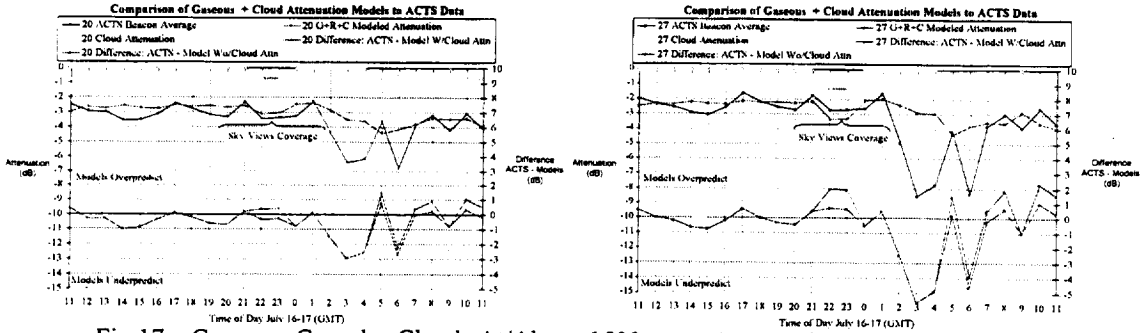


Fig 17 – Compare Cumulus Clouds At/Above 1500 m vs. Averaged ACTS Beacon Values

Another type of cloud is that of a cumulus at a lower elevation, however this time about the cloud is at a ceiling of 500 meters and there is no rain present in the path. The comparison for this type of NCDC defined cloud type is shown in Fig. 18. Note in this case addition of cloud attenuation alters the difference and provides a better fit to the ACTS data.

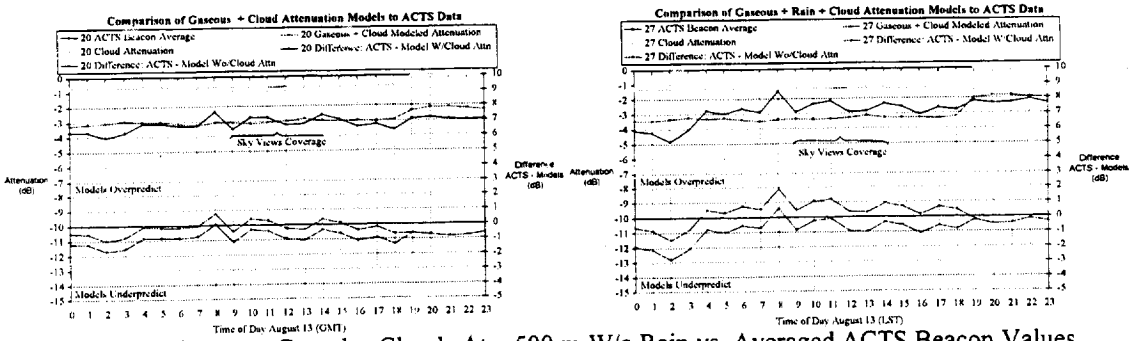


Fig 18 – Compare Cumulus Clouds At ~ 500 m W/o Rain vs. Averaged ACTS Beacon Values

Another type of cloud examined is that of a stratocumulus. Fig. 19 shows the comparisons for this type of cloud structure. Again the addition of the cloud attenuation improves the fit to the recorded ACTS data.

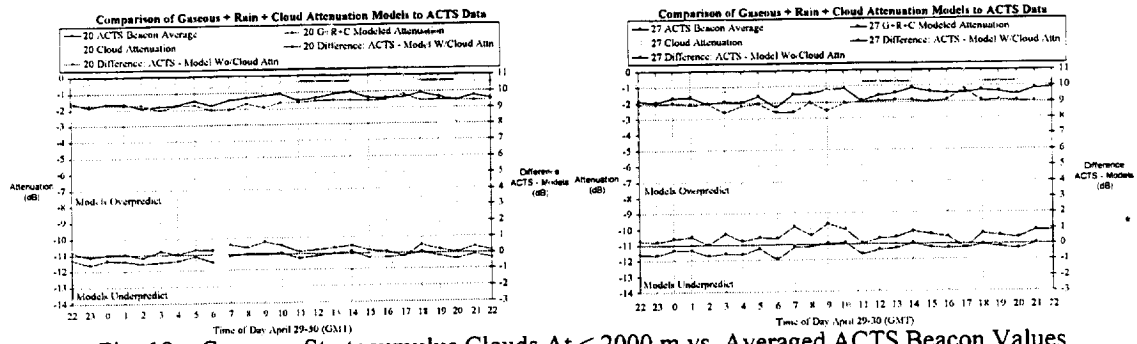


Fig. 19 – Compare Stratocumulus Clouds At < 2000 m vs. Averaged ACTS Beacon Values

The final type of cloud examined is that of an altostratus. This comparison is shown in Fig. 20. In this case the cloud attenuation is not of significant effect and does not significantly improve the fit.

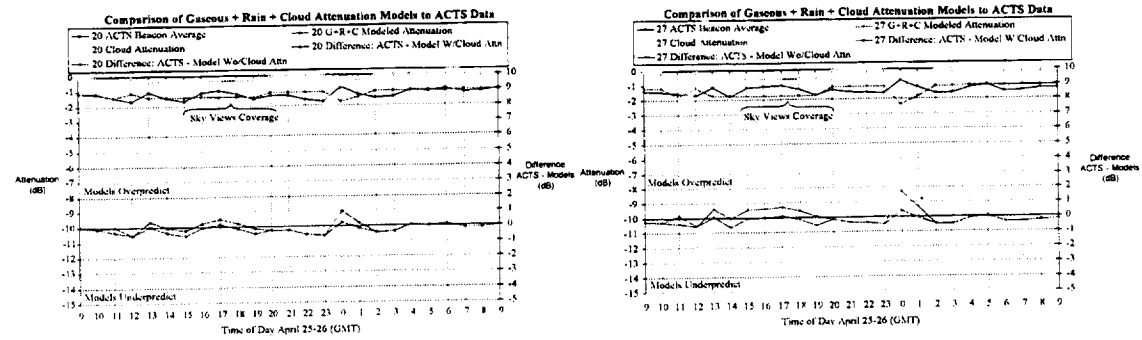


Fig. 20 – Compare Altostratus Clouds 2000 < h < 2900 m vs. Averaged ACTS Beacon Values

G. Statistical Analysis of the Models

Up until now the values of attenuation have been evaluated relative to the ACTS averaged beacons, however many systems designers like to see statistics on the data. To compile a statistical analysis the Averaged ACTS beacon values are divided into 'bins' where values greater than a set attenuation value are collected and then a percentage is taken over the data set total, this is commonly known as a CDF. Fig. 21 shows the set of CDF data collected for the three types of modeled attenuation and the of the averaged ACTS data. As is shown in the figure, the 27 GHz models indeed do a very good job of predicting the attenuation of the ACTS-to-Fairbanks although the 20 GHz comparison is not as good, still represents a fair estimate of the link propagation statistics.

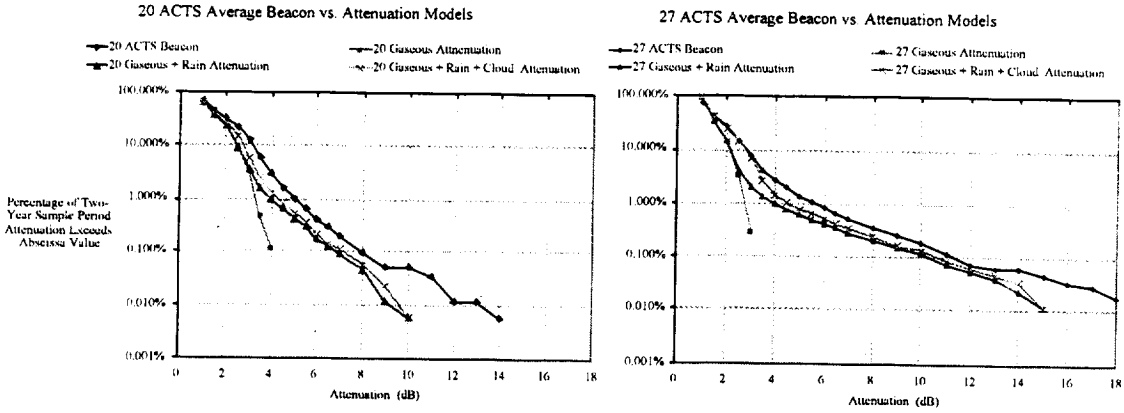


Fig. 21 -- CDF of ACTS Averaged Beacons vs. Modeled Attenuation

IV. Conclusions

The Ortgies-N scintillation prediction model best matches the ACTS data at Fairbanks, out of the seven models that we examined.

The Matricciani fade model was shown to underpredict both the number of fades and fade time for clear air attenuation. Subjectively, the magnitudes of the prediction errors are smaller for this model than for other fade prediction models.

In this study it is shown how NCDC weather data may be used with accepted CCIR gaseous and rain attenuation models and do a good job of estimating the actual ACTS performance for the ACTS–to–Fairbanks link. However with the addition of an empirically defined cloud attenuation model, the data fit is even better. Individual cloud types are examined and attenuation during specific cloud occurrences is determined. An interesting conclusion is that while the additional cloud attenuation by itself is not significant (when compared to gaseous and rain attenuation), it provides enough adjustment to improve the overall CDF. The end result is that given easily available NCDC weather data (with slight alterations), and CCIR gaseous and rain attenuation models along with an empirically defined cloud attenuation model, a reasonable prediction of the performance of satellite to ground propagation characteristics at ACTS frequencies can be made.

APPENDIX A - Calculation of Power Law Parameters for Matricciani Fade Duration Model at Fairbanks

$\phi = 64.86$

$h = 0.4$

$H_s(\phi) = 5.0 - 0.075 \cdot (\phi - 23.0)$

$H_o(\phi) = H_s(\phi) - h$

$H_r = 0.13716$

$\theta = \frac{7.92 \cdot 2 \cdot \pi}{360}$

$L_s = \frac{H_o(\phi) - H_r}{\sin(\theta)}$

$L_s = \frac{H_s(\phi) - H_r}{\sin(\theta)}$

$r = 3.134$

$\Delta x_{ll} = \frac{h}{\tan(\theta)}$

$\alpha = \frac{64.86 \cdot 2 \cdot \pi}{360}$

$\beta = \frac{(260 - (360 - 147.82)) \cdot 2 \cdot \pi}{360}$

$\tau = a\tan\left(\frac{\tan(\alpha)}{\tan(\beta)}\right)$

Using Maggiori [9] power law parameters for 20 °C at 20, 25, and 30 GHz the interpolations for 20.185 and 27.505 GHz are:

$$kh20 = 10^{\left(\log\left(\frac{.124}{.0751}\right)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)}+\log(0.0751)\right)}$$

$$kv20 = 10^{\left(\log\left(\frac{.113}{.0691}\right)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)}+\log(0.0691)\right)}$$

$$\alpha h20 = (1.061 - 1.099)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)} + 1.099$$

$$\alpha v20 = (1.03 - 1.065)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)} + 1.065$$

$k20 = \frac{(kh20 - kv20) + (kh20 - kv20)\cdot\cos(\theta)^2\cdot\cos(\tau\cdot 2)}{2}$

$k20 = 0.071226363$

$\alpha 20 = \frac{kh20\cdot\alpha h20 + kv20\cdot\alpha v20 + (kh20\cdot\alpha h20 - kv20\cdot\alpha v20)\cdot\cos(\theta)^2\cdot\cos(2\cdot\tau)}{2\cdot k20}$

$\alpha 20 = 1.0677614815$

$$kh27 = 10^{\left(\log\left(\frac{.187}{.124}\right)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)}+\log(0.124)\right)}$$

$$kv27 = 10^{\left(\log\left(\frac{.167}{.113}\right)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)}+\log(0.113)\right)}$$

$$\alpha h27 = (1.021 - 1.061)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)} + 1.061$$

$$\alpha v27 = (1.00 - 1.03)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)} + 1.03$$

$$k27 = \frac{(kh27 - kv27) + (kh27 - kv27)\cdot\cos(\theta)^2\cdot\cos(\tau\cdot 2)}{2}$$

$$k27 = 0.1403958942$$

$$\alpha 27 = \frac{kh27\cdot\alpha h27 + kv27\cdot\alpha v27 + (kh27\cdot\alpha h27 - kv27\cdot\alpha v27)\cdot\cos(\theta)^2\cdot\cos(2\cdot\tau)}{2\cdot k27}$$

$$\alpha 27 = 1.0175416272$$

Using Maggiori [9] power law parameters for 0 °C at 20, 25, and 30 GHz the interpolations for 20.185 and 27.505 GHz are:

$$kh20 = 10^{\left(\log\left(\frac{.1159}{.06772}\right)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)}+\log(0.06772)\right)}$$

$$kv20 = 10^{\left(\log\left(\frac{.1028}{.06097}\right)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)}+\log(0.06097)\right)}$$

$$\alpha h20 = (1.081 - 1.119)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)} + 1.119$$

$$\alpha v20 = (1.054 - 1.084)\cdot\frac{\log\left(\frac{20.185}{20}\right)}{\log\left(\frac{25}{20}\right)} + 1.054$$

$$k20 = \frac{(kh20 - kv20) + (kh20 - kv20)\cdot\cos(\theta)^2\cdot\cos(\tau\cdot 2)}{2}$$

$$k20 = 0.0630989053$$

$$\alpha 20 = \frac{kh20\cdot\alpha h20 + kv20\cdot\alpha v20 + (kh20\cdot\alpha h20 - kv20\cdot\alpha v20)\cdot\cos(\theta)^2\cdot\cos(2\cdot\tau)}{2\cdot k20}$$

$$\alpha 20 = 1.0710708332$$

$$kh27 = 10^{\left(\log\left(\frac{.1811}{.1159}\right)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)}+\log(0.1159)\right)}$$

$$kv27 = 10^{\left(\log\left(\frac{.159}{.1028}\right)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)}+\log(0.1028)\right)}$$

$$\alpha h27 = (1.035 - 1.081)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)} + 1.035$$

$$\alpha v27 = (1.018 - 1.054)\cdot\frac{\log\left(\frac{27.505}{25}\right)}{\log\left(\frac{30}{25}\right)} + 1.018$$

$$k27 = \frac{(kh27 - kv27) + (kh27 - kv27)\cdot\cos(\theta)^2\cdot\cos(\tau\cdot 2)}{2}$$

$$k27 = 0.1311683662$$

$$\alpha 27 = \frac{kh27\cdot\alpha h27 + kv27\cdot\alpha v27 + (kh27\cdot\alpha h27 - kv27\cdot\alpha v27)\cdot\cos(\theta)^2\cdot\cos(2\cdot\tau)}{2\cdot k27}$$

$$\alpha 27 = 1.0006591497$$

APPENDIX B - Calculation of CCIR-Defined Gaseous Attenuation

CCIR Gaseous (Oxygen &Water Vapor) Attenuation Model Equations for f < 57 GHz:

$$\alpha_o = \left[7.19\cdot 10^{-3} + \frac{6.09}{f^2 + 0.227} + \frac{4.81}{(f-57)^2 + 1.5}\right]\cdot f^2\cdot 10^{-3}\left[\frac{dB}{km}\right]$$

$$\alpha_w = \left[0.05 + 0.0021\cdot\rho + \frac{3.6}{(f-22.2)^2 + 8.5} + \frac{10.6}{(f-183.3)^2 + 9} + \frac{8.9}{(f-325.4)^2 + 26.3}\right]\cdot f^2\cdot\rho\cdot 10^{-4}\left[\frac{dB}{km}\right]$$

$$h_o = 6\ km \qquad h_w = h_{wO}\cdot\left[1 + \frac{3}{(f-22.2)^2 + 5} + \frac{5}{(f-183.3)^2 + 6} + \frac{2.5}{(f-325.4)^2 + 4}\right]\cdot(km)$$

where: $h_{wO} = 1.6\cdot km\cdot(clear\_weather) = 2.1\cdot km\cdot(rain)$ $\qquad R_w = 461\cdot\left[\frac{joule}{kg\cdot K}\right]$

$$\rho = RH\cdot\frac{e_s}{R_w\cdot(T+273)}\cdot\left[\frac{g}{m^3}\right] \qquad e_s = \frac{5854\cdot 10^{\left(20 - \frac{2950}{273+T}\right)}}{(273+T)^5}\cdot(millibars) \qquad RH = Relative\_Humidity\ (\%)$$

Correction Factors for Temperature Variances (Stated Range of Accuracy -20 °C to 40 °C):

$$\alpha_{oZ} = \alpha_o - 0.01\cdot\alpha_o\cdot(T - 15\cdot°C) \qquad \alpha_{wZ} = \alpha_w - 0.01\cdot\alpha_w\cdot(T - 15\cdot°C)$$

$$h_{oZ} = h_o - 0.01\cdot h_o\cdot(T - 15\cdot°C) \qquad h_{wZ} = h_w - 0.01\cdot h_w\cdot(T - 15\cdot°C)$$

Zenith Attenuation:

$$A_Z = \alpha_o\cdot h_o + \alpha_w\cdot h_w$$

Correction for Non-Zenith Propagation Paths With Elevation Angles $\theta < 10°$:

$$A_\theta = \frac{\sqrt{R}}{\cos(\theta)}\left[\alpha_o\cdot\sqrt{h_o}\cdot F\left[\tan(\theta)\cdot\sqrt{\frac{R}{h_o}}\right] + \alpha_w\cdot\sqrt{h_w}\cdot F\left[\tan(\theta)\cdot\sqrt{\frac{R}{h_w}}\right]\right]\cdot(dB)$$

where: $F(x) = \frac{1}{0.661\cdot x + 0.339\cdot\sqrt{x^2 + 5.51}}$

APPENDIX C - Calculation of CCIR-Defined Rain Attenuation

CCIR Rain Attenuation Model Equations For ACTS Beacons (20.185 GHz Shown):

Evaluation of Site Tilt Angle τ: $\alpha \equiv$ Earth_Station_Latitude $\beta \equiv$ Satellite_Longitude − Earth_Station_Longiude

$\tau := \operatorname{atan}\left[\frac{\tan(\alpha)}{\sin(\beta)}\right]$ $\tau = 70.70093 \cdot deg$ $\alpha \equiv 64.7 \cdot deg$ $\beta \equiv (360 - 100) \cdot deg - (360 - 147.8) \cdot deg$

(+ Northern Hemisphere) (Measured in Degrees East)

$\theta \equiv 8 \cdot deg$ (Elevation Angle)

Calculate the Regression Coefficients Used in The Calculations, k and α.

$k_{1H} \equiv 0.0751$ $k_{2H} \equiv 0.124$ $f_1 \equiv 20$ $f_2 \equiv 25$ $\alpha_{1H} \equiv 1.099$ $\alpha_{2H} \equiv 1.061$

$k_{1V} \equiv 0.0691$ $k_{2V} \equiv 0.113$ $\alpha_{1V} \equiv 1.065$ $\alpha_{2V} \equiv 1.030$

$$k_H := 10^{\left[\log\left[\frac{k_{2H}}{k_{1H}}\right] \cdot \frac{\log\left[\frac{20.185}{f_1}\right]}{\log\left[\frac{f_2}{f_1}\right]} + \log(k_{1H})\right]}$$

$k_H = 0.07667$

$$k_V := 10^{\left[\log\left[\frac{k_{2V}}{k_{1V}}\right] \cdot \frac{\log\left[\frac{20.185}{f_1}\right]}{\log\left[\frac{f_2}{f_1}\right]} + \log(k_{1V})\right]}$$

$k_V = 0.07052$

$$\alpha_H := (\alpha_{2H} - \alpha_{1H}) \cdot \frac{\log\left[\frac{20.185}{f_1}\right]}{\log\left[\frac{f_2}{f_1}\right]} + \alpha_{1H}$$

$\alpha_H = 1.09743$

$$\alpha_V := (\alpha_{2V} - \alpha_{1V}) \cdot \frac{\log\left[\frac{20.185}{f_1}\right]}{\log\left[\frac{f_2}{f_1}\right]} + \alpha_{1V}$$

$\alpha_V = 1.06356$

$$k_{20.185} := \frac{k_H + k_V + (k_H - k_V) \cdot \cos(\theta \cdot deg)^2 \cdot \cos(2 \cdot \tau)}{2}$$

$k_{20.185} = 0.07119$

$$\alpha_{20.185} := \frac{k_H \cdot \alpha_H + k_V \cdot \alpha_V + (k_H \cdot \alpha_H - k_V \cdot \alpha_V) \cdot (\cos(\theta \cdot deg)^2 \cdot \cos(2 \cdot \tau))}{2 \cdot k_{20.185}}$$

Values of α & k:

$\alpha_{20.185} = 1.06754$

Site Information: $\phi \equiv 64.7$ (Station Latitude)

$\theta \equiv 8 \cdot deg$ (Elevation Angle)

Calculations: $h_s \equiv 580 \cdot ft$ (Station Elevation)

Find the freezing height during rain (h_{fr}):

$h_{fr} := [5.0 - 0.075 \cdot (\phi - 23)] \cdot km$ (For Latitudes > 23°)

Find the effective path length (L_S): $h_{fr} - h_s = 1.696 \cdot km$

$$L_S := \frac{(h_{fr} - h_s)}{\sin(\theta)}$$

$L_S = 12.184 \cdot km$

APPENDIX D - Calculation of Cloud Attenuation

Specific attenuation due to clouds is of the form: $\gamma_c(f) = 0.182 \cdot f \cdot N''_w(f) \left(\frac{dB}{km}\right)$

Where: f = frequency in GHz

N''_w is the imaginary part of the complex refractivity in ppm (10^{-6}) $N''_w = \frac{9}{2} \cdot \frac{w}{\varepsilon'' \left(1 + \eta^2\right)}$

Where w is the liquid water density in g/m^3 and: $\eta = \frac{(2 + \varepsilon')}{\varepsilon''}$

Where ε' and ε'' are the real and imaginary parts of the permitivity of water:
(The double Debye relaxation model gives the dielectric spectra for water as below)

$$\varepsilon'(f) = \varepsilon_2 + \frac{\varepsilon_0 - \varepsilon_1}{1 + \left(\frac{f}{f_p}\right)^2} + \frac{\varepsilon_1 - \varepsilon_2}{1 + \left(\frac{f}{f_s}\right)^2} \qquad \varepsilon''(f) = \frac{f \cdot (\varepsilon_0 - \varepsilon_1)}{f_p \left[1 + \left(\frac{f}{f_p}\right)^2\right]} + \frac{f \cdot (\varepsilon_1 - \varepsilon_2)}{f_s \left[1 + \left(\frac{f}{f_s}\right)^2\right]}$$

Where:

f = frequency (GHz) $\varepsilon_0 = 77.66 + 103.3\ (\theta - 1)$ $\varepsilon_1 = 5.48$ $\varepsilon_2 = 3.51$

$f_p = 20.09 - 142\ (\theta - 1) + 294\ (\theta - 1)^2$ (GHz) $f_s = 590 - 1500\ (\theta - 1)$ (GHz)

Where: $\theta = \frac{300}{T}$ and T is temperature in Kelvin

Liquid water content is found from: $w = w_o (1 + c \cdot t) \left(\frac{h_c}{h_r}\right)^a p_w(T) \left(\frac{g}{m^3}\right)$

Where:

w_o is the liquid water content of the cloud $\left(\frac{g}{m^3}\right)$ $p_w(t) = \begin{cases} 1 & 0\ ^\circ C < t \\ 1 + \frac{t}{20} & -20\ ^\circ C < t < 0\ ^\circ C \\ 0 & t < -20\ ^\circ C \end{cases}$

$c = 0.041 \left(\frac{1}{^\circ C}\right)$ t = Temperature (°C)

h_c = height from cloud base (m) a = 1.4

h_r = reference height (m) (In this evaluation $h_r = h_c$ eliminating the middle term)

$$\text{Distance (km)} = \frac{\text{Effective\_Path(km)}}{\sin(8^\circ)}$$

$$\text{Attenuation (dB)} = \text{Distance (km)} \cdot \gamma_c(f) \left(\frac{dB}{km}\right)$$

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CRC / UBC

UBC ACTS Terminal Operation and Maintenance

Bruce Dow,
Scientific Engineer,
UBC Electrical and
Computer Engineering

ACTS Propagation Studies Workshop, Oklahoma City, 22-23 October, 1998

CRC / UBC

UBC ACTS Terminal Operation and Maintenance

- **Terminal Operation and Maintenance Summary from June, 1998, to October, 1998.**
- **Preprocessing and Calibration Issues.**
- **Summary**

Terminal Operation and Maintenance Summary

- **The Collection Computer and associated ACTS laboratory setup were moved from the Fourth Floor to the Penthouse of the Electrical Engineering Building.**

- **This was accomplished with less than one half-hour of total downtime.**

Terminal Operation and Maintenance Summary

- **The Young capacitive rain gauge was received back from being repaired and calibrated, and was re-installed on the roof. Correct operation and calibration were verified.**

- **The amplifier enclosure of the CTS-10 Coordinated Time Link antenna was opened, inspected, cleaned out, and sealed with silicone seal before being put back into service. This preventative maintenance was suggested by Mr. Westenhaver.**

Terminal Operation and Maintenance Summary

- **A 48-hour power outage was scheduled for the Electrical Engineering Building. In order to maintain data collection during this time, a long extension cord was run from an adjacent building to power the terminal. This solution was suggested by Mr. Westenhaver.**

Preprocessing and Calibration Issues

- **Weather data for the first three years was obtained from Vancouver International Airport in electronic form. We now have Airport data for the first four years.**

- **Mr. Westenhaver converted the weather data into *.SRF files for use with ACTPP.**

Preprocessing and Calibration Issues

- CRC decided to have the entire first four years of data from UBC preprocessed again by Xuhe Wang of the University of Oklahoma.

- Electronic copies of the site logs were sent to Xuhe Wang along with the *.SRF files.

Preprocessing and Calibration Issues

- **Collaboration between the University of Oklahoma and UBC ensured a consistent treatment of past and future data. This included reaching an agreement on the proper calibration levels for all data.**

- **After looking at the first four years of data, Dr. Crane and Mr. Westenhaver provided recommendations on how to handle the problem of moisture in the feed horn.**

Summary

- **The terminal is in good condition. No problems are foreseen in collecting the remainder of the five years of data.**

- **Preprocessing of the fifth year of data is underway. Purchasing Airport weather data for the fifth year is being considered.**

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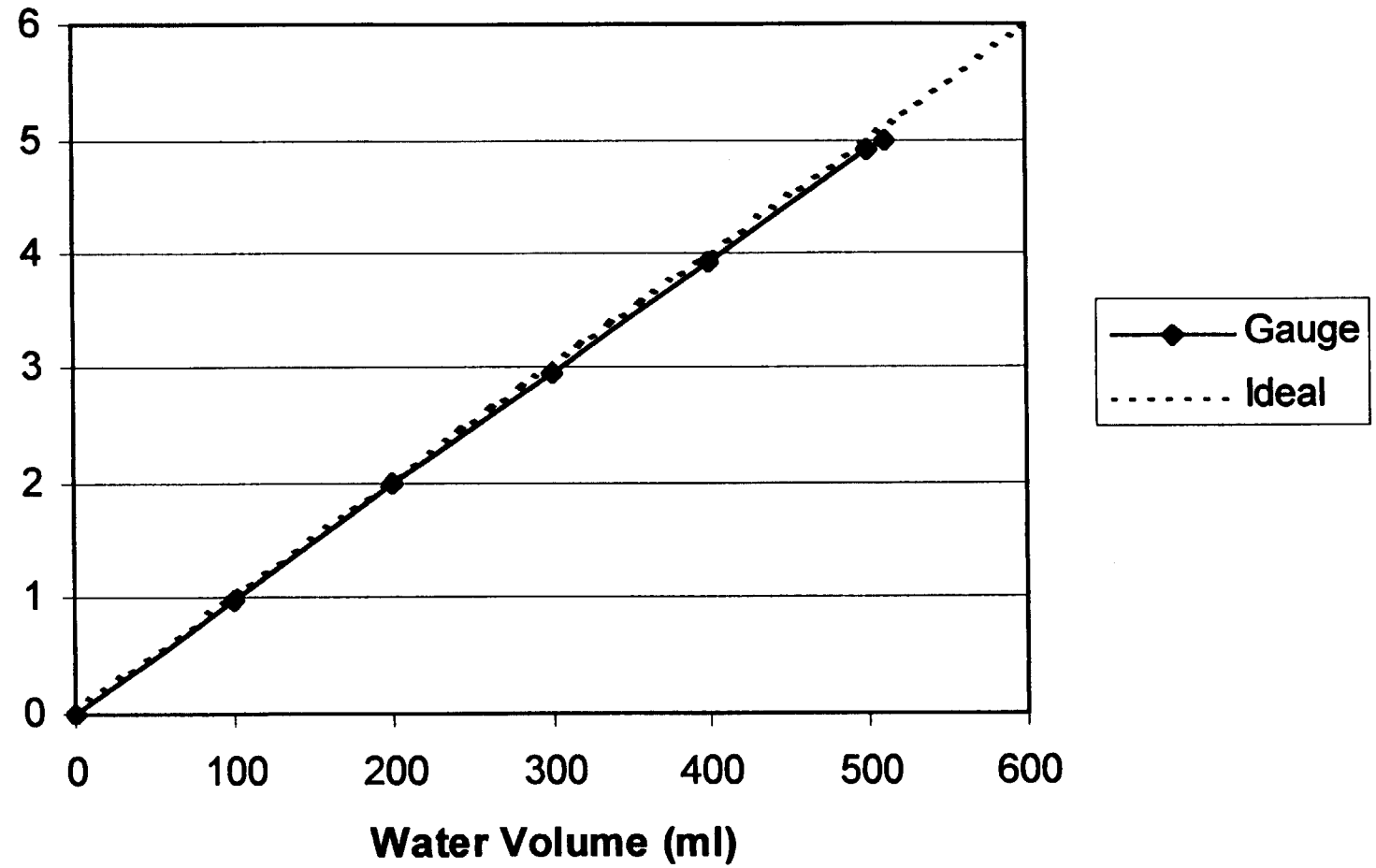
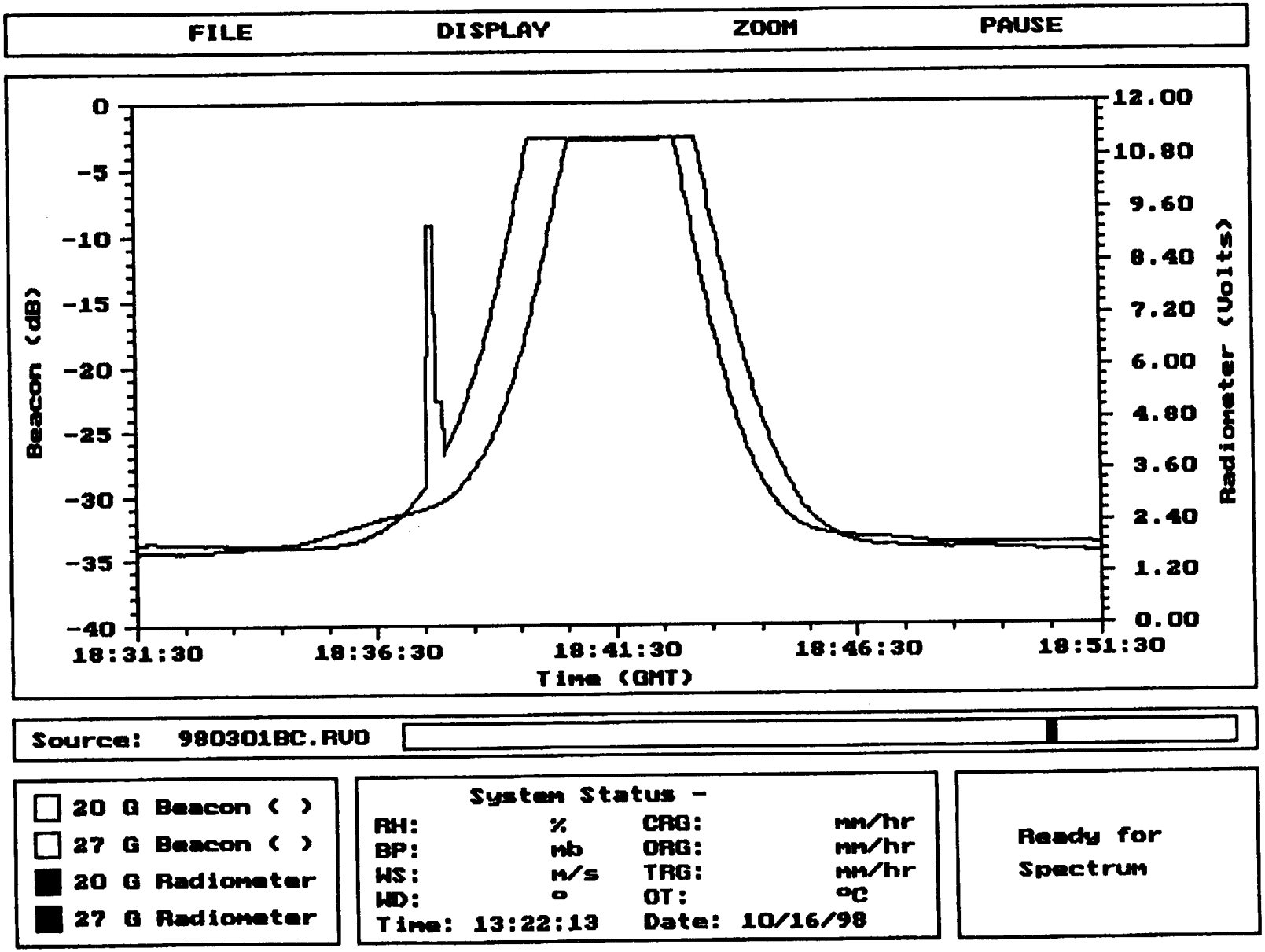
Young Capacitive Rain Gauge Calibration at UBC Site 980721



Old Antenna Pattern



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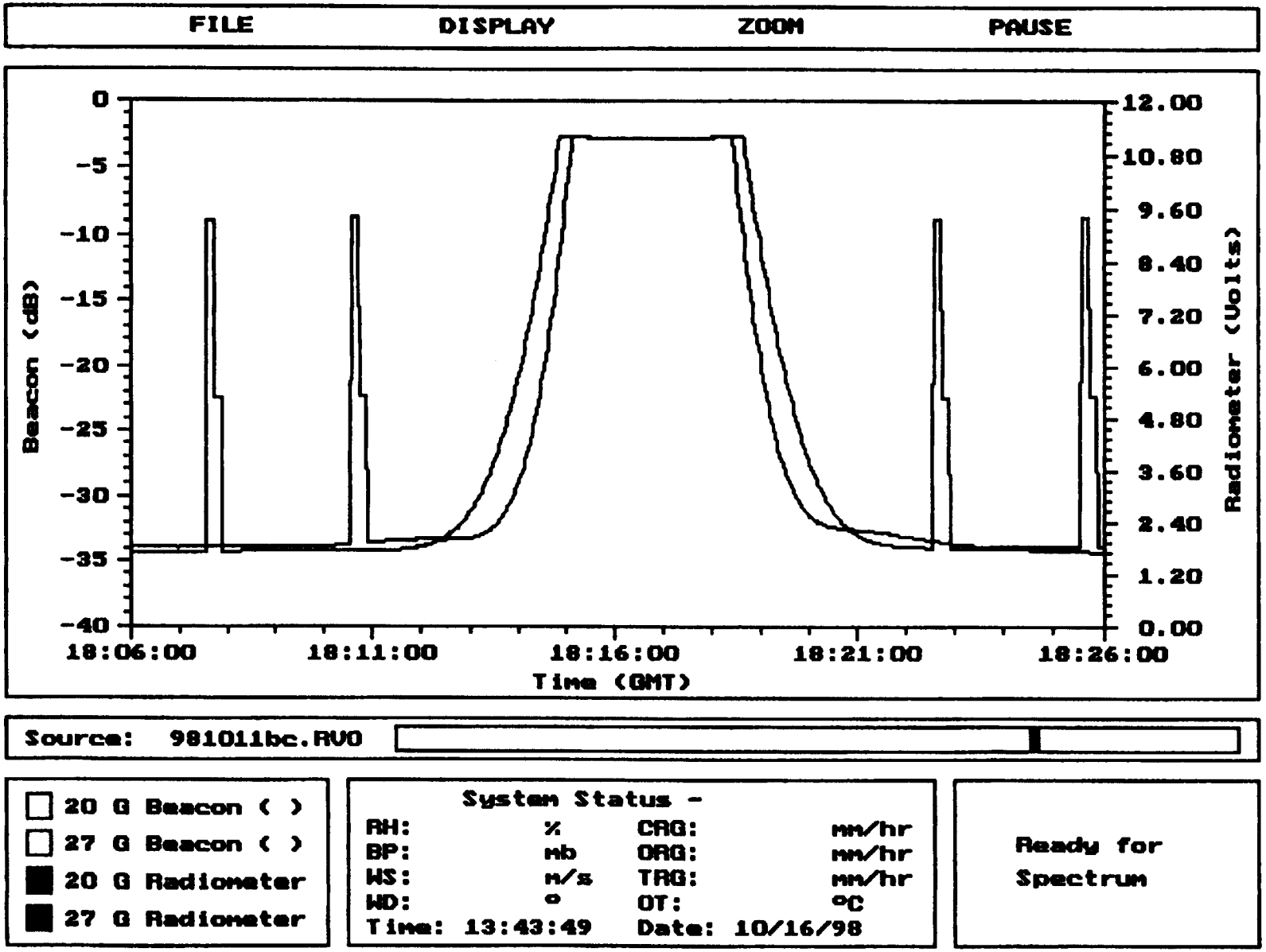
New Antenna Pattern



Four Years of ACTS Propagation Measurements in Vancouver

César Amaya
Communications Research Centre
Ottawa - Canada

CRC Communications Research Centre

ACTS Propagation Measurements in Vancouver

- Climatic characteristics at Vancouver
- Statistics of Attenuation for the Period 1994-1997 using reprocessed data
- Comparison of Measured Statistics with Prediction Models
- Summary

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Climatic characteristics at Vancouver

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Climatic Characteristics at Vancouver

- Pacific maritime climate. Little heavy rain but a great deal of widespread drizzle and lower-rate rainfall
- Long-term annual average rainfall at the Vancouver Int. Airport: about 1020 mm. Average annual snowfall: 60 cm
- Average daily temperature : from 0° to 24° C over the year
- Vancouver falls in rain zone D in the ITU-R classification and in rain zone B1 in the Crane's Global classification
- Measured rain rate level for 0.01% of time : 13 mm/hr (measurements over a ten-year period at the Vancouver International Airport*)

* The Vancouver International Airport is located some 8 km south of the UBC site

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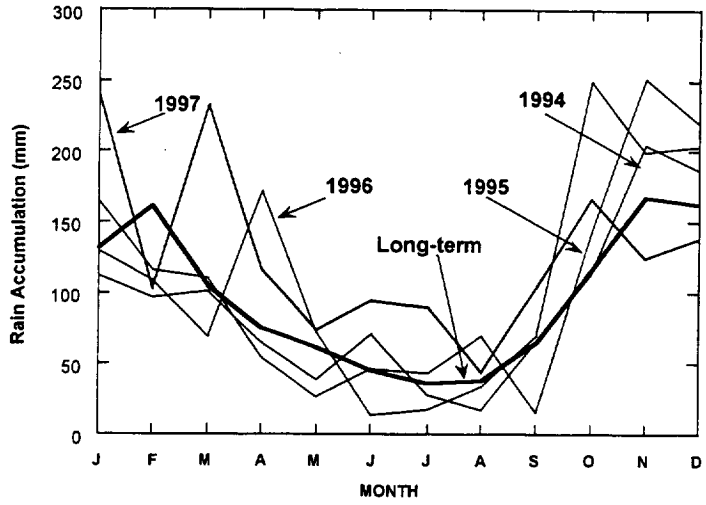
Rain Accumulation at Vancouver 1994-1997



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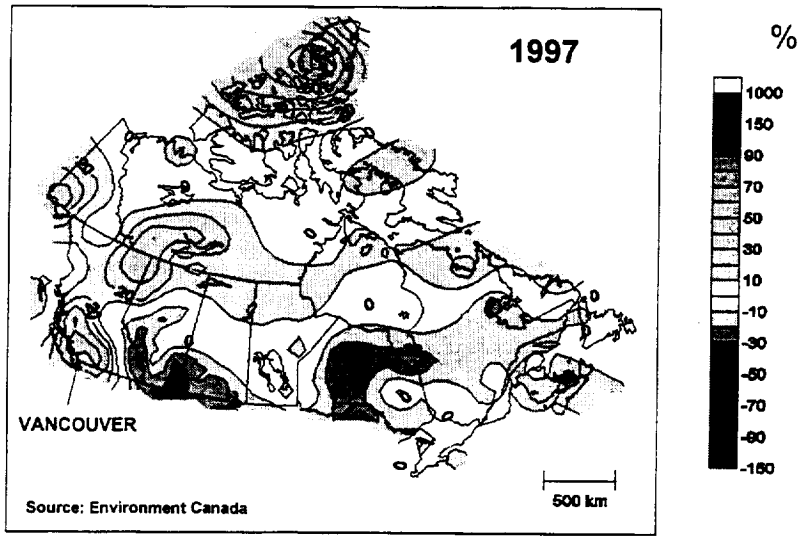
Precipitation Departures from Normal (above/below the average of last 50 Years)



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- Average precipitation and temperature were above normal in 1997 along much of the Pacific Coast
- 1997 averaged about 17% wetter than normal along the Pacific Coast, representing the 2nd wettest year in the last half century
- Temperature was close to two degrees warmer than normal over the course of the year
- 1997 was drier than normal in eastern Canada

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Seasonal and Annual Average Freezing Level Heights

(km above ground level)

Station	Lat. N (deg.)	Long. W (deg.)	Height (m.a.s.l.)	Winter	Spring	Summer	Fall	Annual average	ITU-R formula
Vernon B.C.	50.14	119.17	555	0.89	1.42	**2.71**	1.78	1.70	**2.96**
Port Hardy B.C.	50.41	127.22	22	1.25	1.43	**2.83**	2.18	1.92	**2.92**
Vancouver B.C.	49.15	123.15	164						**3.0**

. Freezing level heights obtained from radiosonde data for the period 1979-1990

. The values obtained utilizing the ITU-R formula agree fairly well with the observed summer heights, otherwise the heights tend to be overestimated

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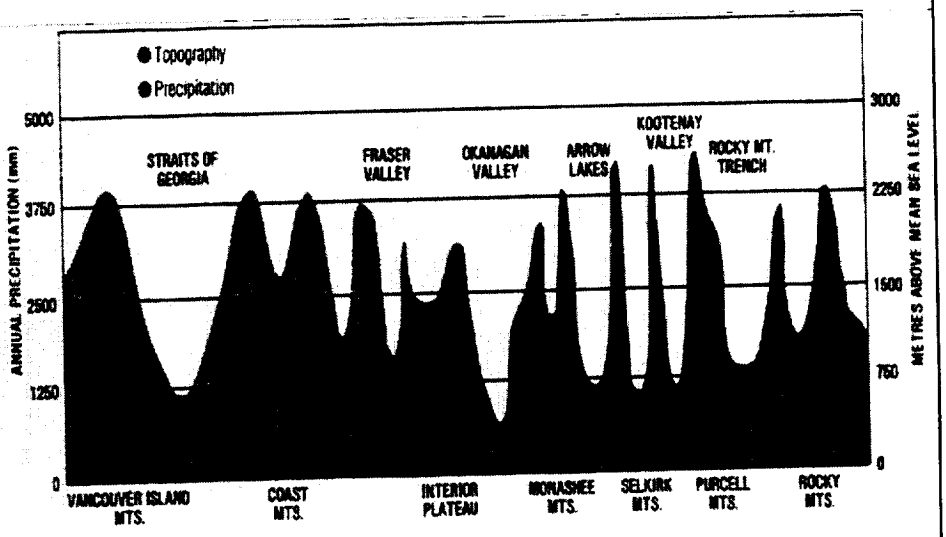
Effect of Topography on Precipitation Across Southern British Columbia



(Adapted from B.C. Atlas of Resources)

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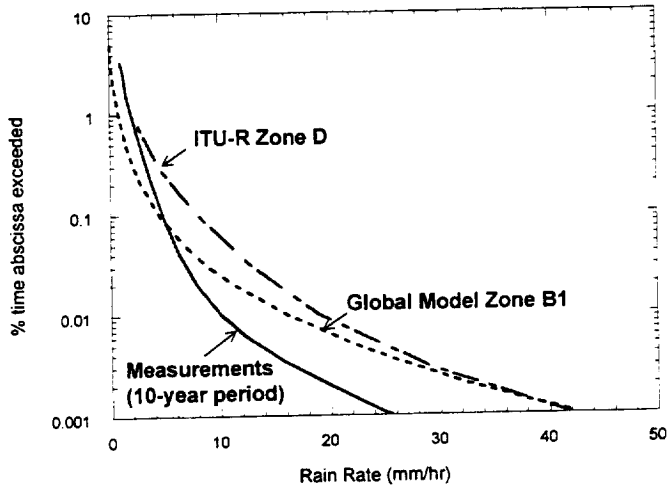
Rain Rate Statistics at Vancouver



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Statistics of Attenuation Using Reprocessed Data 1994-1997

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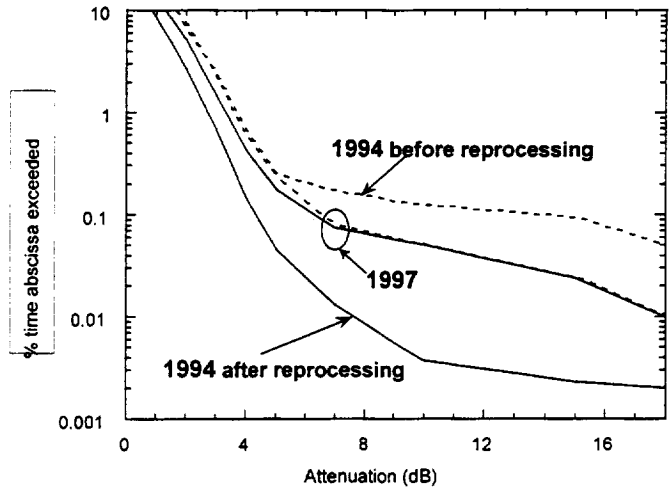
Reprocessed Data
Attenuation wrt Clear Sky - 20 GHz



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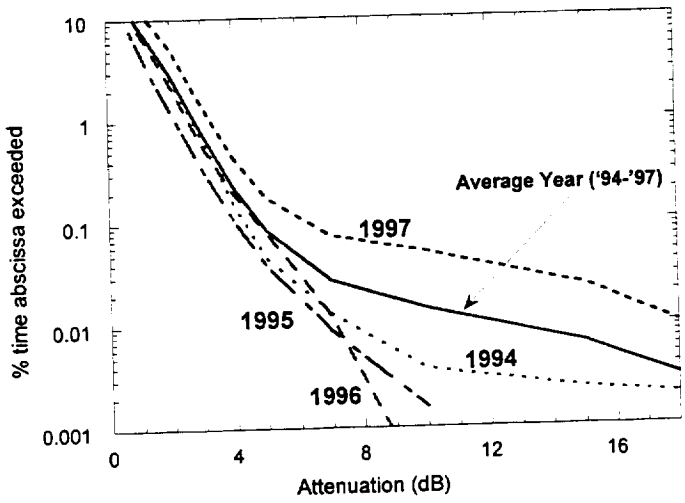
Statistics of Attenuation wrt Clear Sky
Vancouver - 20 GHz



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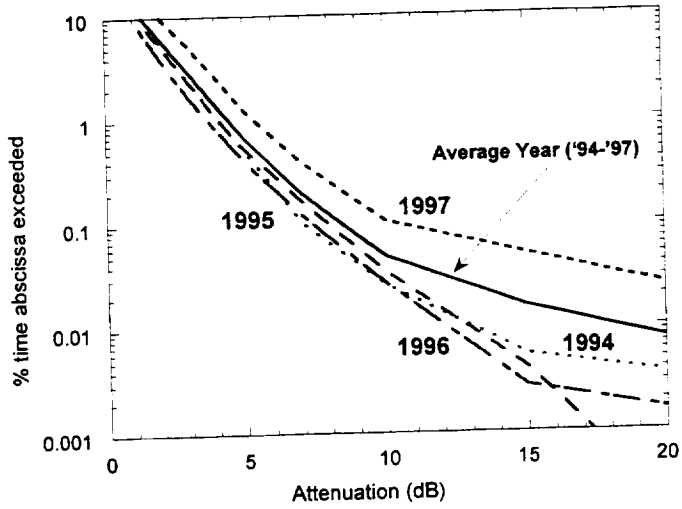
Statistics of Attenuation wrt Clear Sky
Vancouver - 30 GHz



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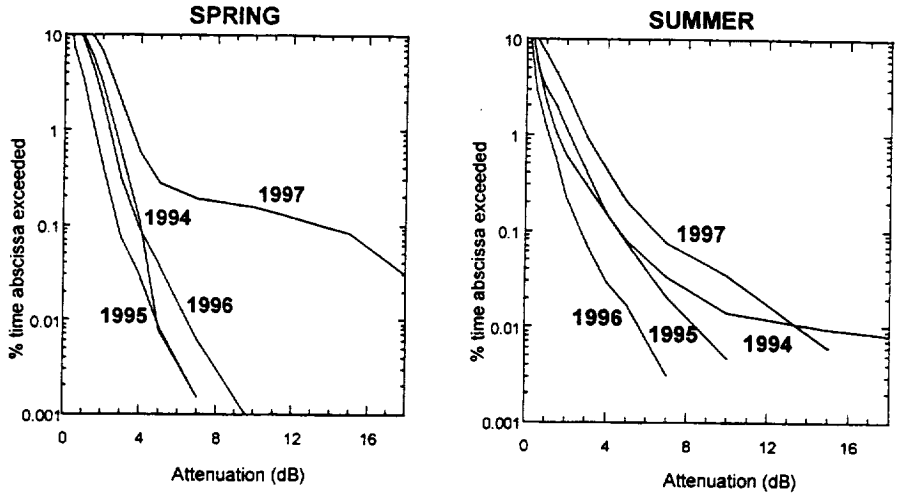
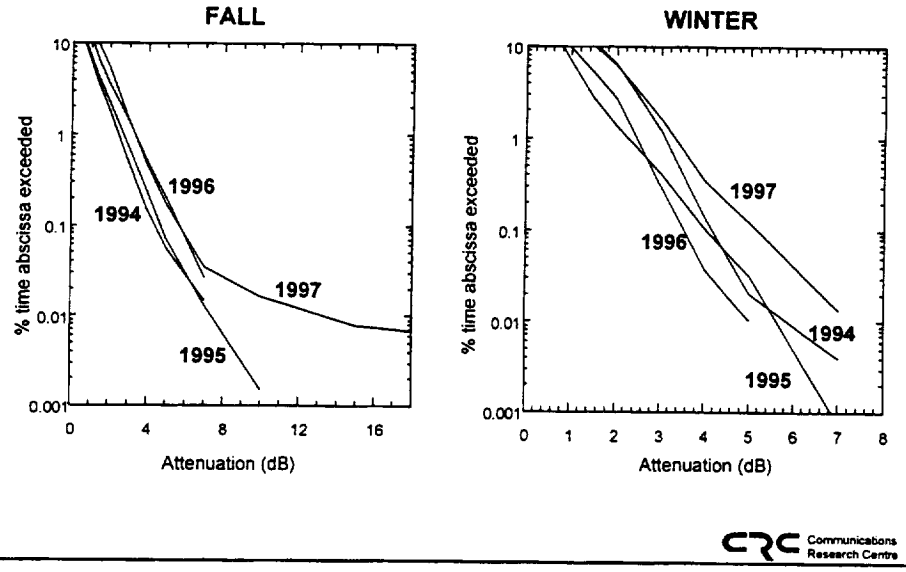
Seasonal Statistics

Attenuation wrt Clear Sky - 20 GHz

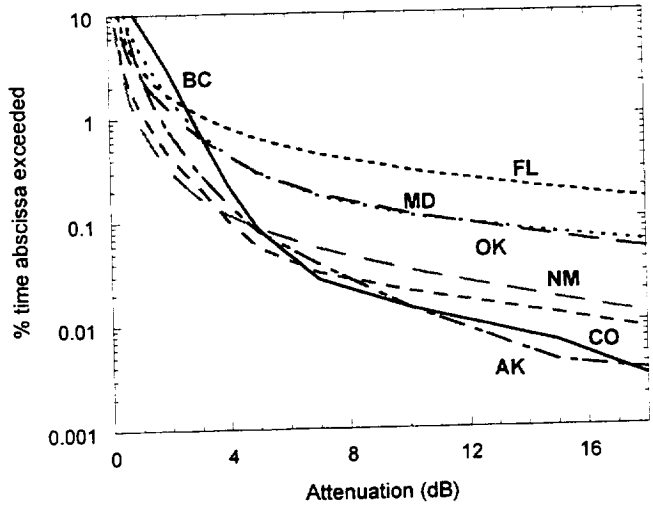


Seasonal Statistics

Attenuation wrt Clear Sky - 20 GHz



Attenuation wrt Clear Sky at 7 Sites 20 GHz



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Statistics of Attenuation

- 1997 clearly dominates the annual and seasonal statistics of attenuation for the period 1994-1997
- Attenuation distributions for 1994, 1995 and 1996 show little interannual variability
- Winter season (December-February) statistics show many small attenuation events of long duration, especially below 5 dB
- The effect of antenna wetting can have an important influence on the measured statistics, especially on statistics for the Winter season

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Comparison of Measured Statistics with Prediction Models

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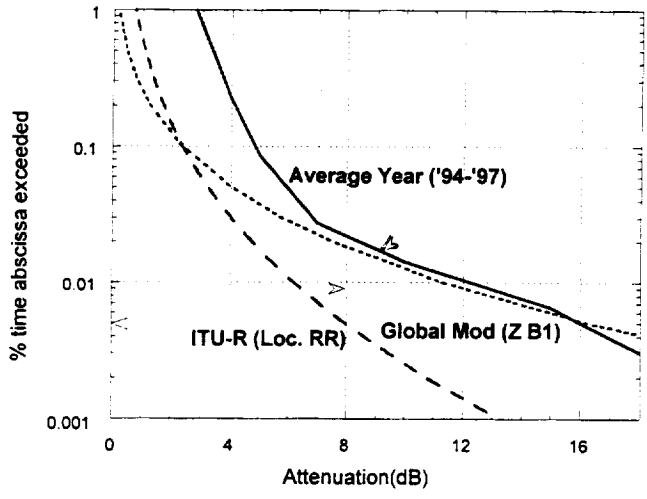
Comparison of Models and Measurements Vancouver - 20 GHz



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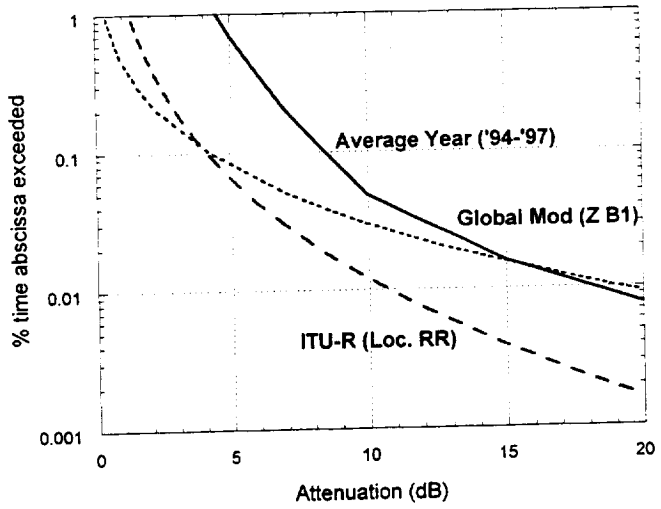
Comparison of Models with Measurements
Vancouver - 30 GHz



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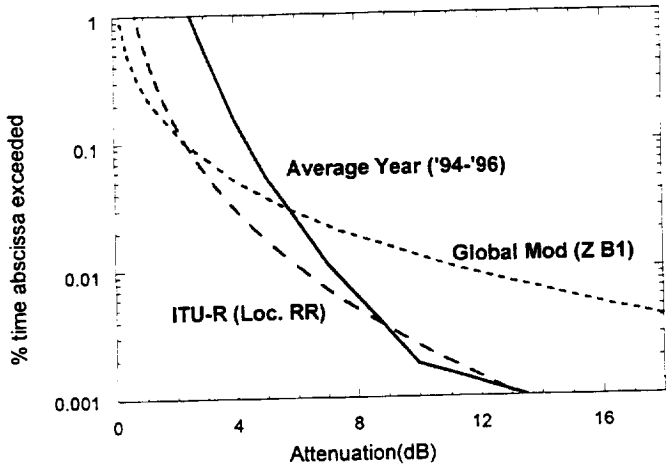
Comparison of Models and Measurements
Vancouver - 20 GHz



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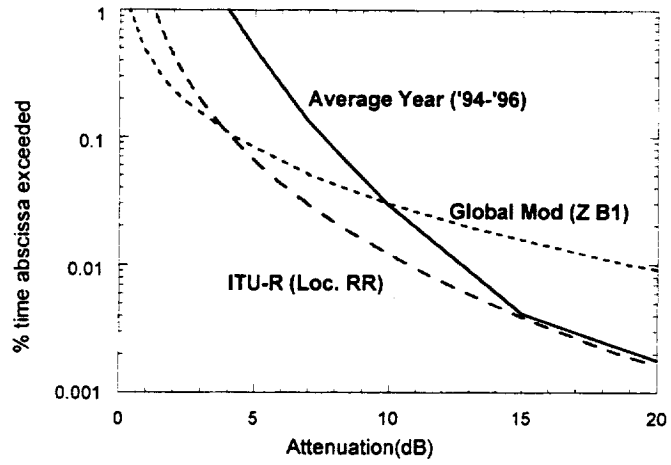
Comparison of Models and Measurements Vancouver - 30 GHz



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Comparison of models with measurements

- Comparison of models with data measured for an average year (period 1994-1997):
  - The ITU-R model clearly underpredicts the attenuation measured at both frequencies
  - The Global model underpredicts the measured data in the region of small attenuation values but measured and model curves agree rather well above about 7 dB (at 20 GHz) and 12 dB (at 30 GHz)
- When models are compared with statistics of an average year for the period 1994-1996, the ITU-R model gives better results than the Global model
- In the region of low attenuation values the measured statistics can be affected by the combined effects of antenna wetting and moisture penetration into the receive antenna feed

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Summary

- Four years of data (1994-1997) recorded at the ACTS-Vancouver site were re-processed by the U. of Oklahoma, improving their quality
- Annual and seasonal attenuation statistics measured at Vancouver during the period 1994-1997 are strongly dominated by the year 1997 when rainfall reached record levels along the South-Pacific coast of Canada
- Comparisons of measured statistics with the ITU-R and the Global rain attenuation prediction models indicates mixed results, with the Global model giving better results when compared with statistics of an average year (period 1994-1997)
- Correction for antenna wetting effects was not yet implemented

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Ka-Band Propagation Studies Using the ACTS Propagation Terminal and the CSU-CHILL Multiparameter Radar

Experimenters

Colorado State University

Department of Electrical Engineering

Fort Collins, CO 80523

Investigators

John Beaver, Research Assoc.

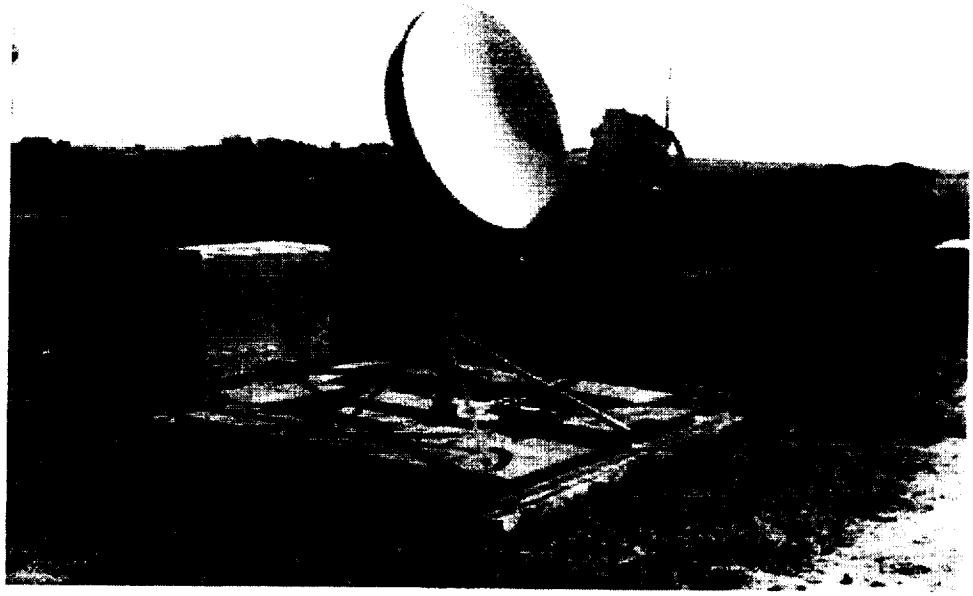
V.N. Bringi, Professor

ACTS Propagation Studies Workshop

October 22-23, 1998

Oklahoma City, OK

CSU-APT Site Location



- CSU-APT is located about 30 km southeast of Fort Collins near LaSalle, Colorado (approx. 13 km south of the CSU-CHILL radar)
- APT elevation angle - 43 deg
- APT azimuth angle - 173 deg
- Altitude 1.52 km

Outline

- CSU-APT Status Report
  - Terminal Update
  - Processing Update

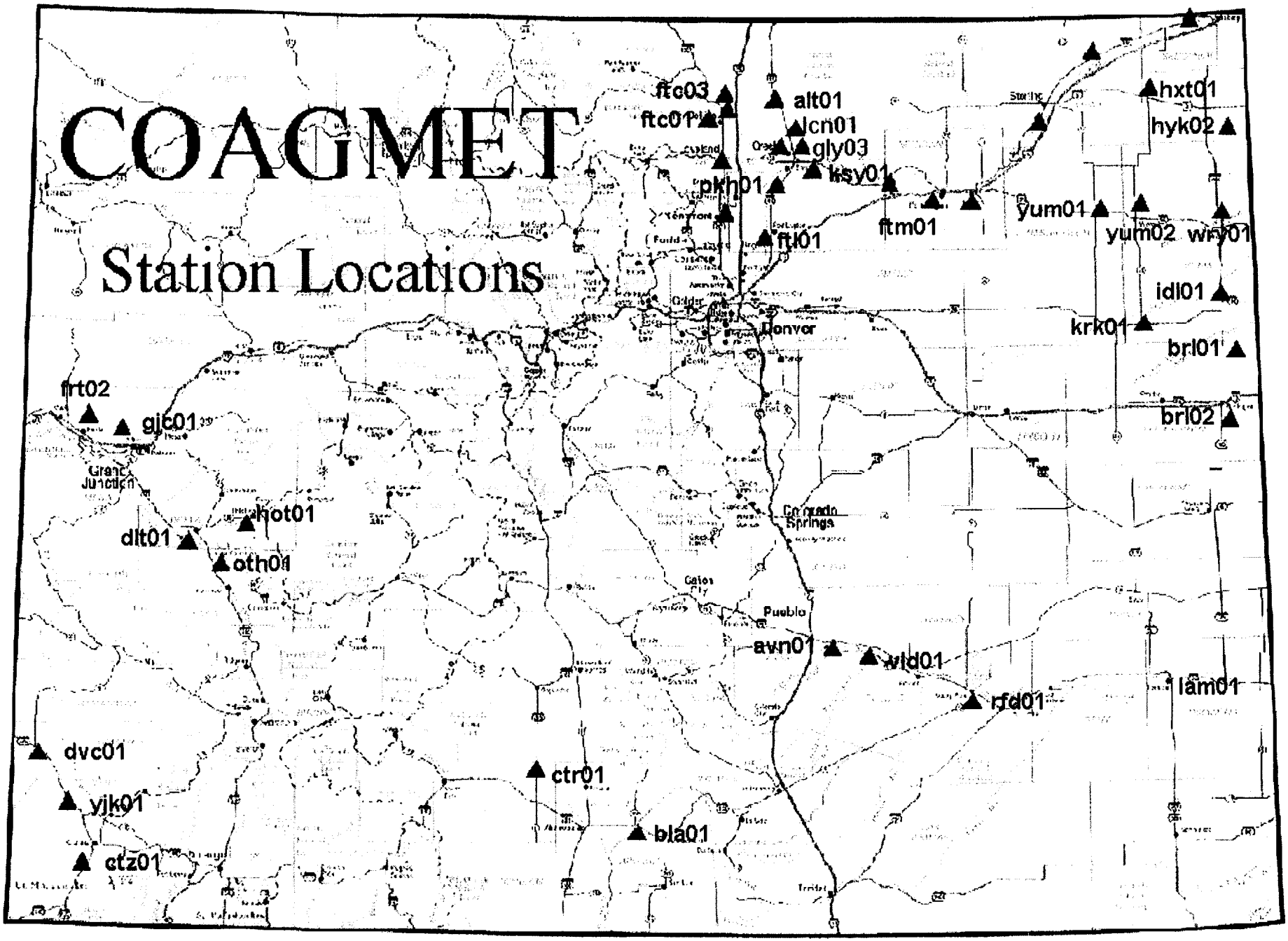
- CSU-APT Attenuation Data
  - Comparison of data using APT weather files and external weather files
  - 1998 Data
  - Comparisons using local rain data for 1994

- Preliminary Melting Layer Studies

CSU-APT Status Report

- Terminal Status
  - replacement of WWV time card solved rebooting problems (re-seating the card was solution)
  - no major problems with collection system

- Processing Status
  - Data through August 1998 have been processed
  - Data from October 1994 through May 1996 have been reprocessed using external weather


COAGMET
Station Locations
ftc03
ftc01
alt01
lcn01
gly03
lsy01
pkh01
ftl01
ftm01
hxt01
hyk02
yum01
yum02
wry01
idl01
krk01
brl01
brl02
Denver
frt02
gjc01
Grand Junction
hot01
dlt01
oth01
Colorado Springs
Pueblo
avn01
vld01
rfd01
lam01
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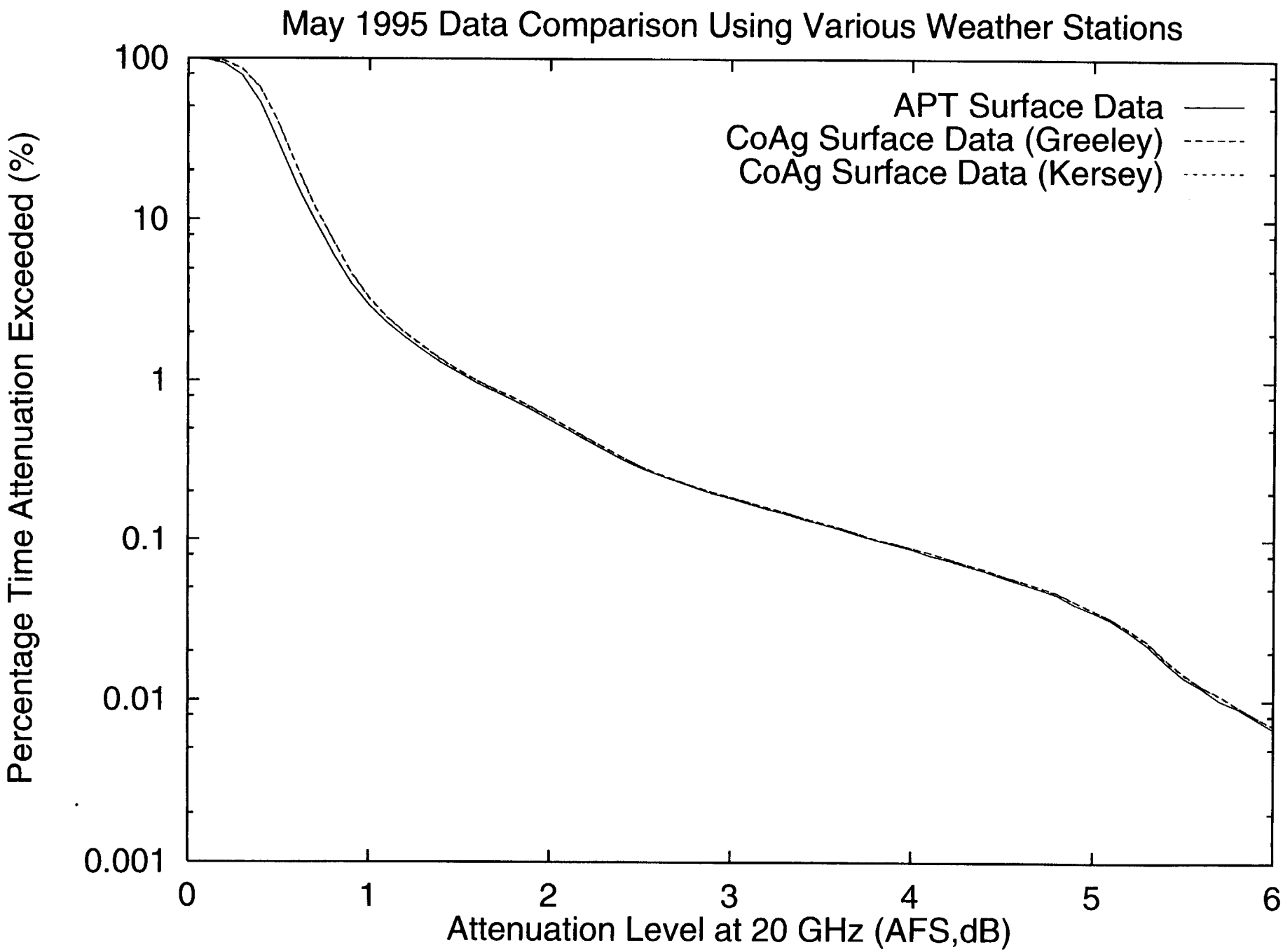
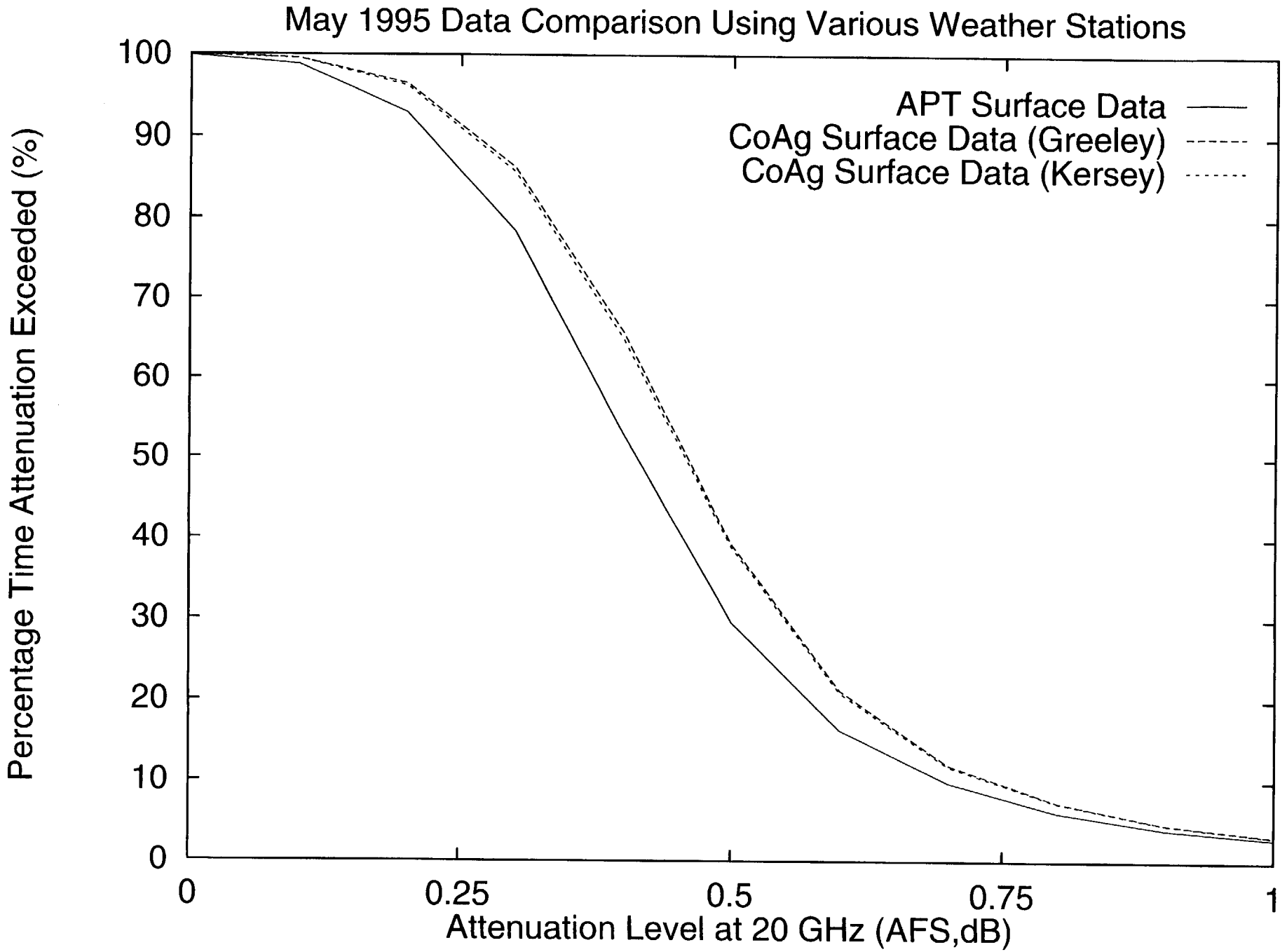
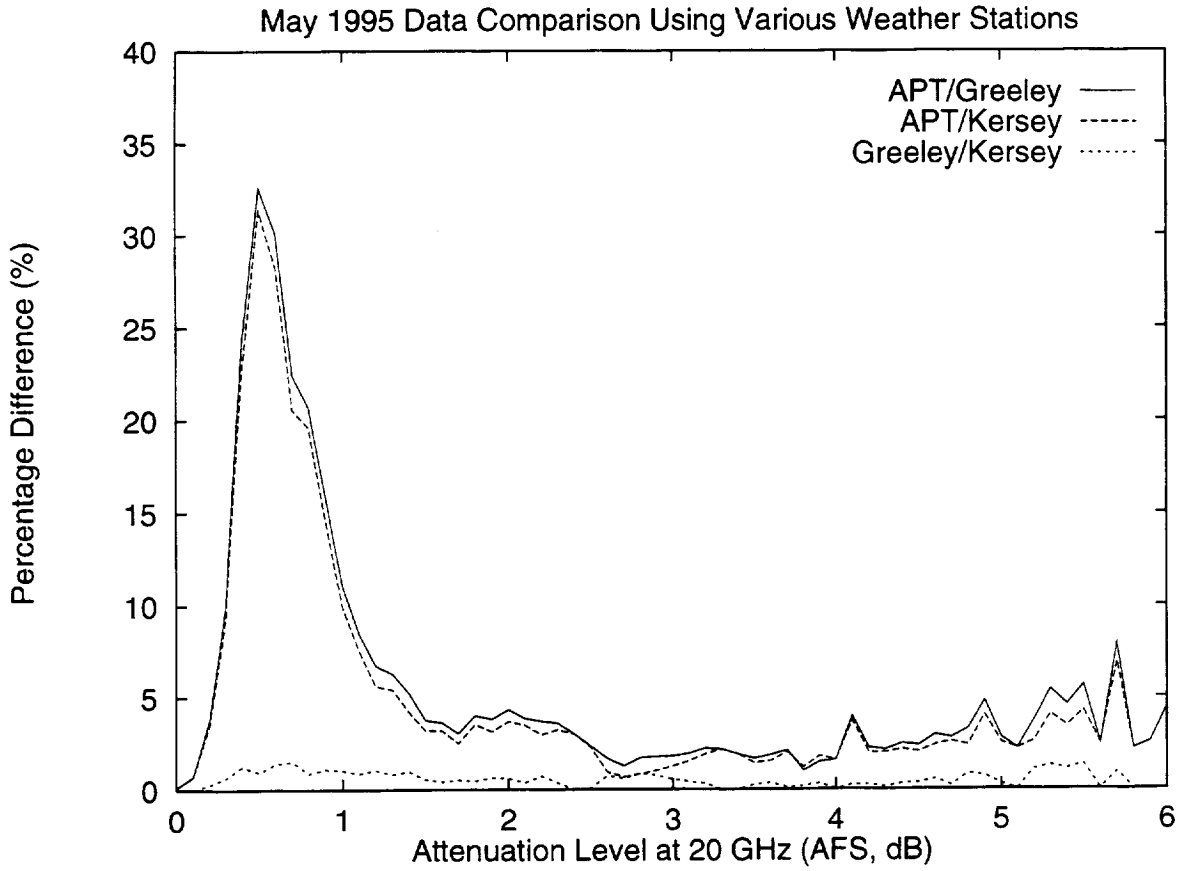
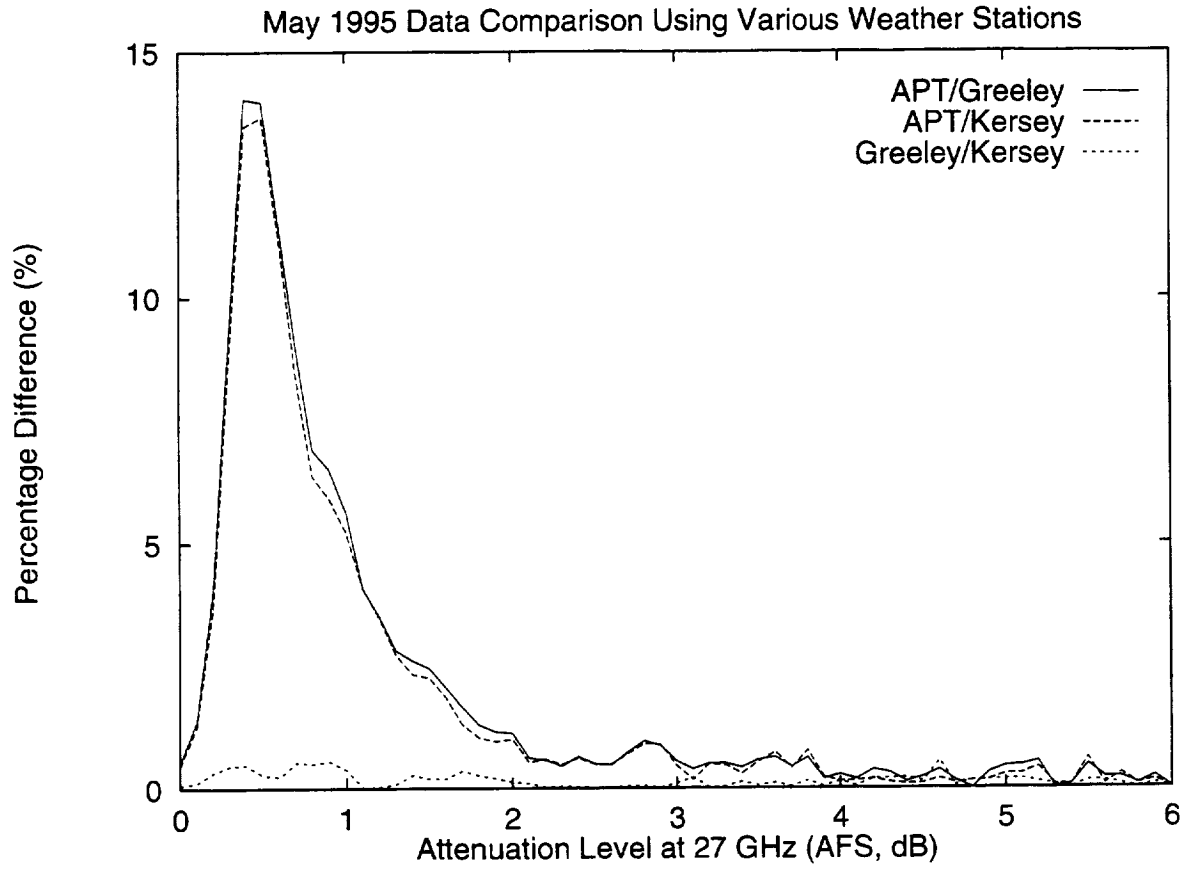
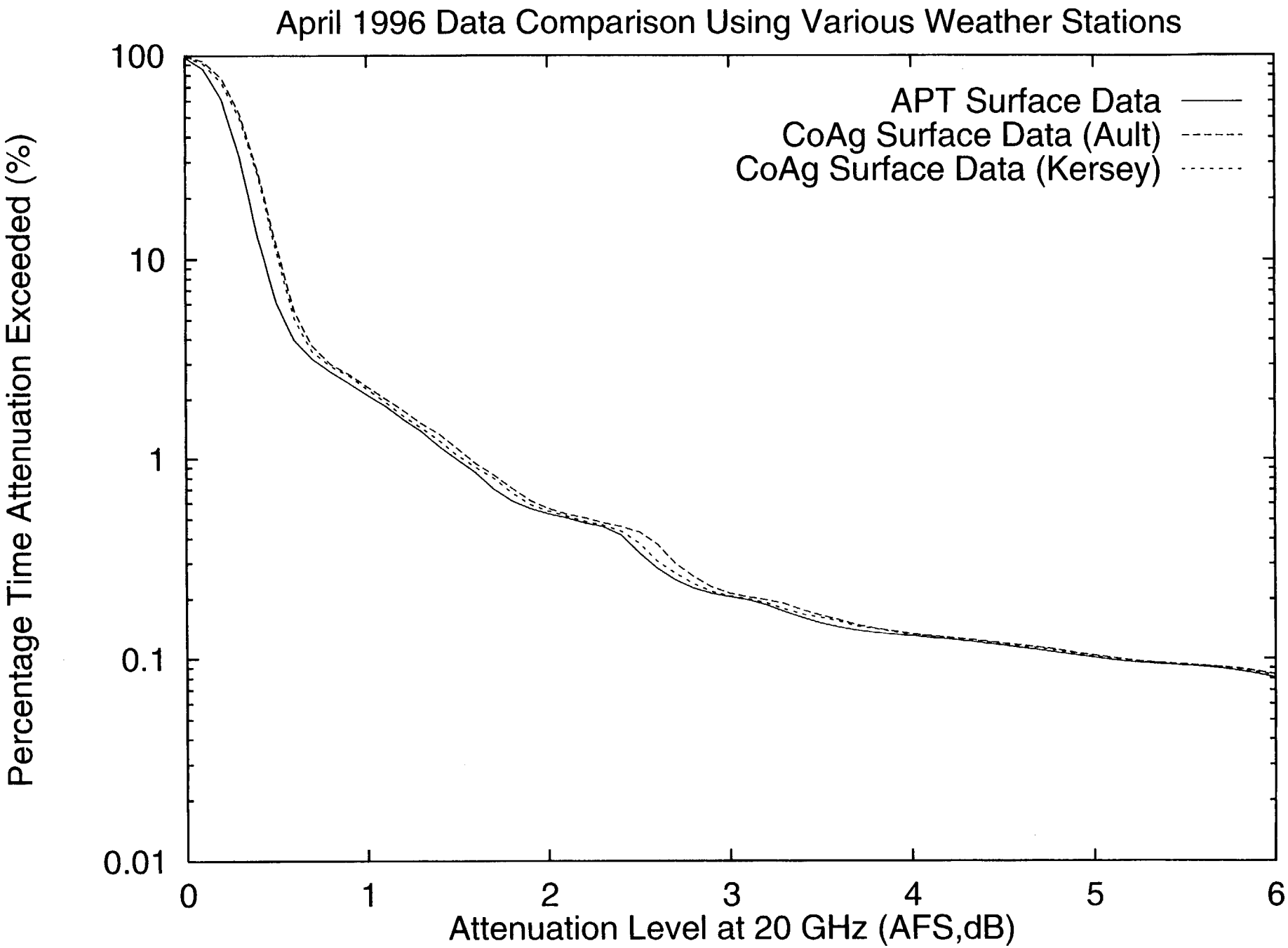
ctr01
bla01

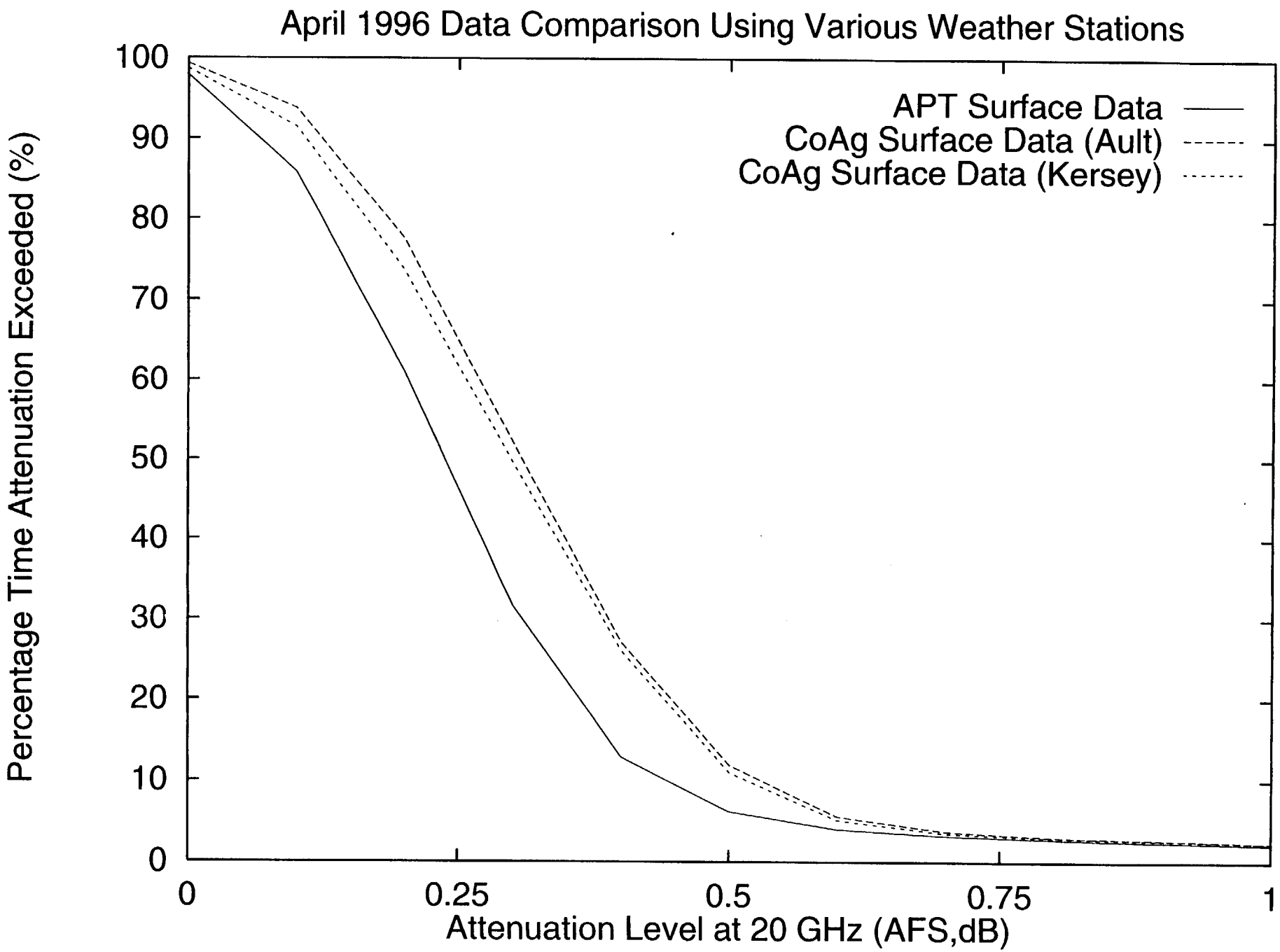

May 1995 Data Comparison Using Various Weather Stations
APT Surface Data
CoAg Surface Data (Greeley)
CoAg Surface Data (Kersey)
Percentage Time Attenuation Exceeded (%)
100
10
1
0.1
0.01
0.001
0
1
2
3
4
5
6
Attenuation Level at 20 GHz (AFS,dB)

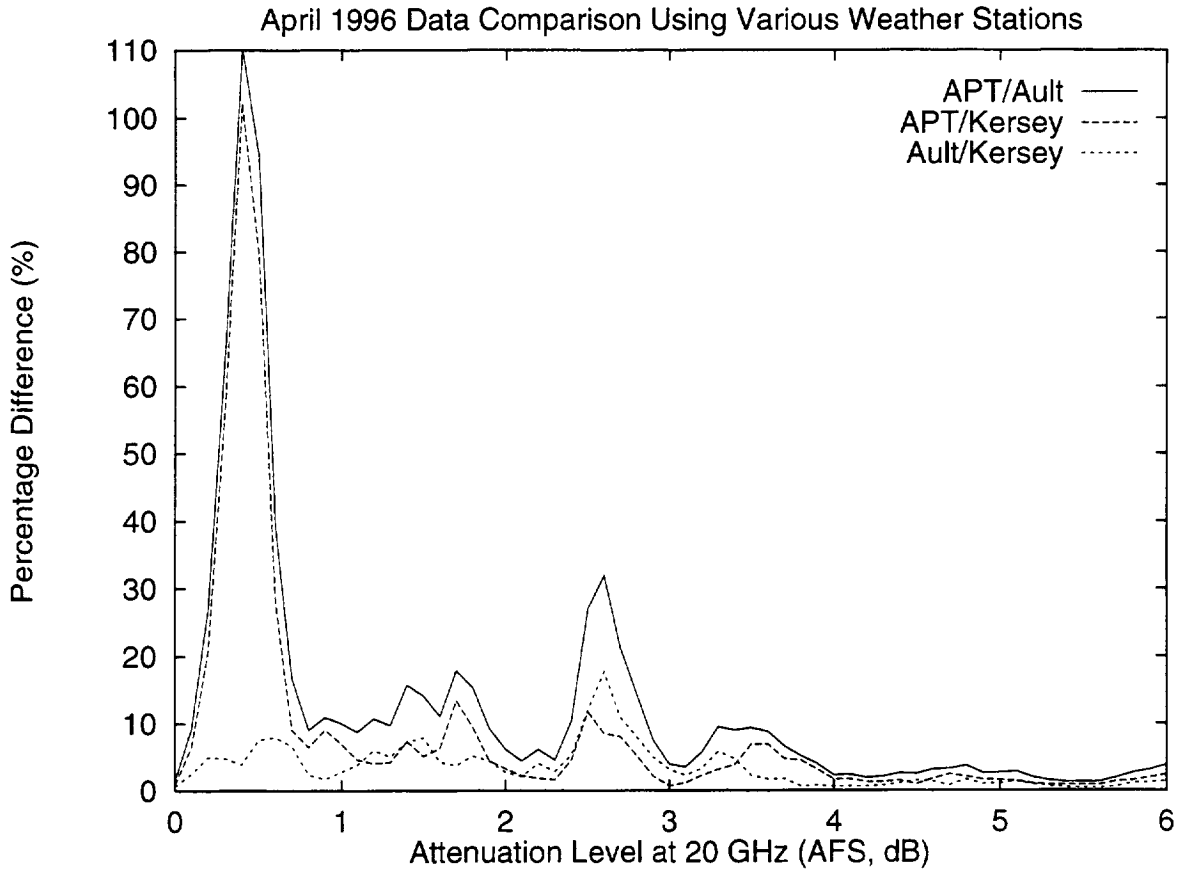

May 1995 Data Comparison Using Various Weather Stations
APT Surface Data
CoAg Surface Data (Greeley)
CoAg Surface Data (Kersey)
Percentage Time Attenuation Exceeded (%)
100
90
80
70
60
50
40
30
20
10
0
0
0.25
0.5
0.75
1
Attenuation Level at 20 GHz (AFS,dB)

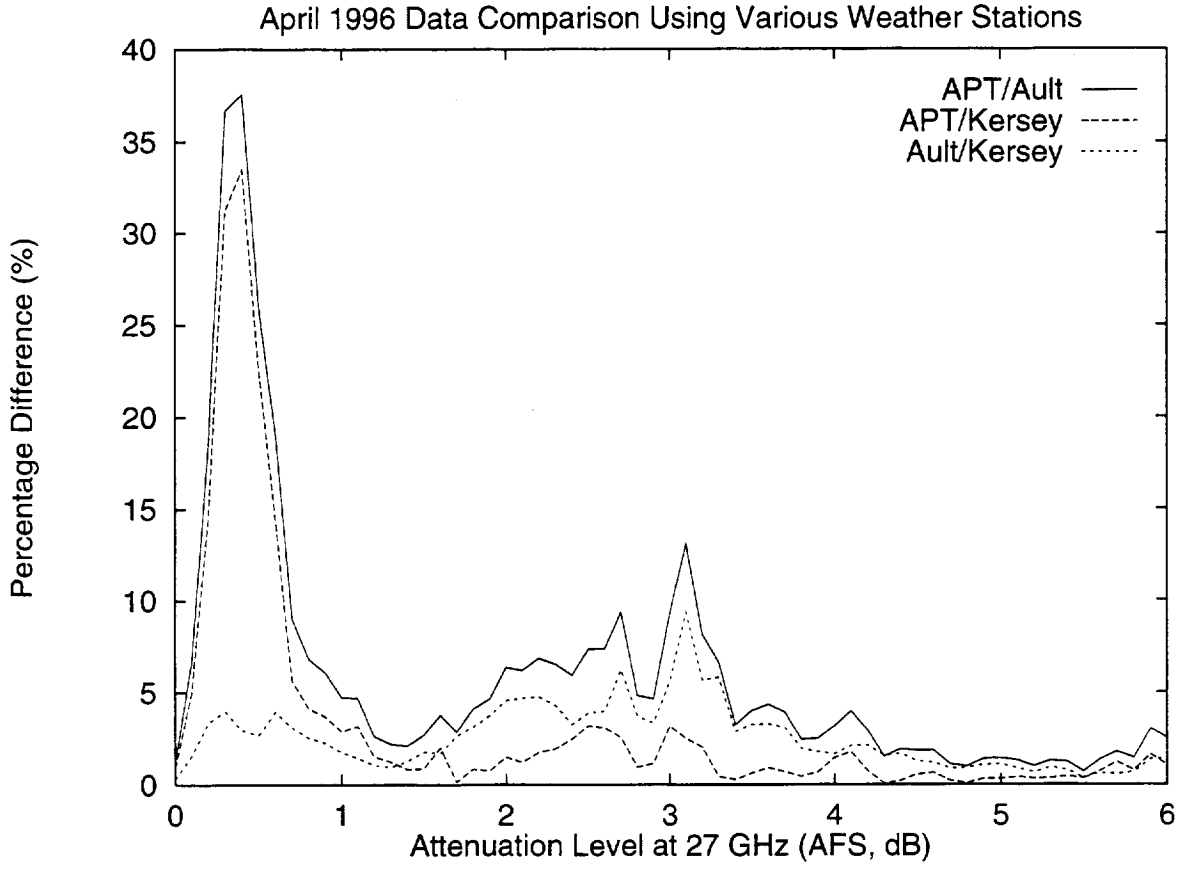

May 1995 Data Comparison Using Various Weather Stations
APT/Greeley
APT/Kersey
Greeley/Kersey
Percentage Difference (%)
Attenuation Level at 20 GHz (AFS, dB)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6

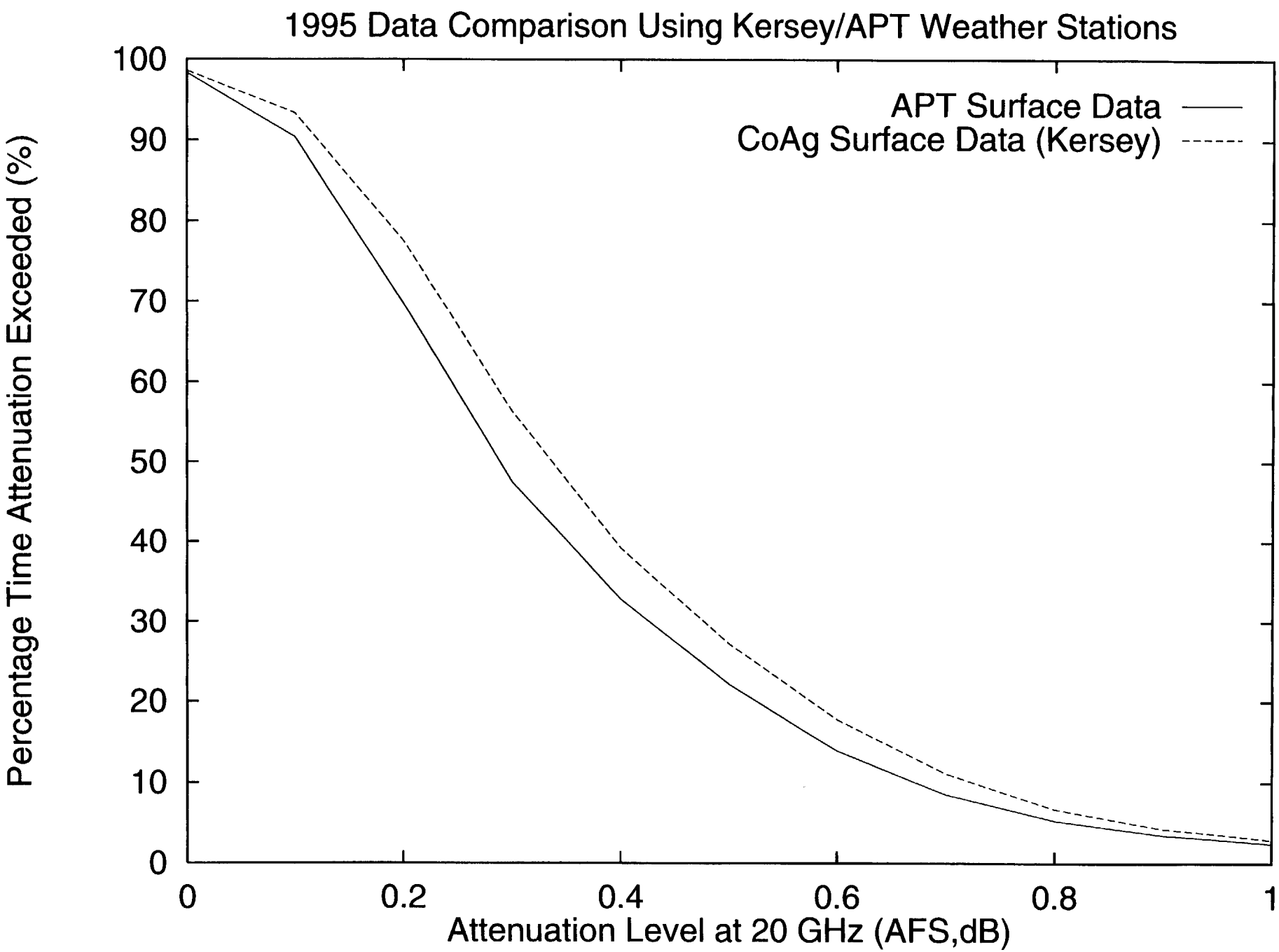

May 1995 Data Comparison Using Various Weather Stations
APT/Greeley
APT/Kersey
Greeley/Kersey
Percentage Difference (%)
Attenuation Level at 27 GHz (AFS, dB)
0
5
10
15
0
1
2
3
4
5
6

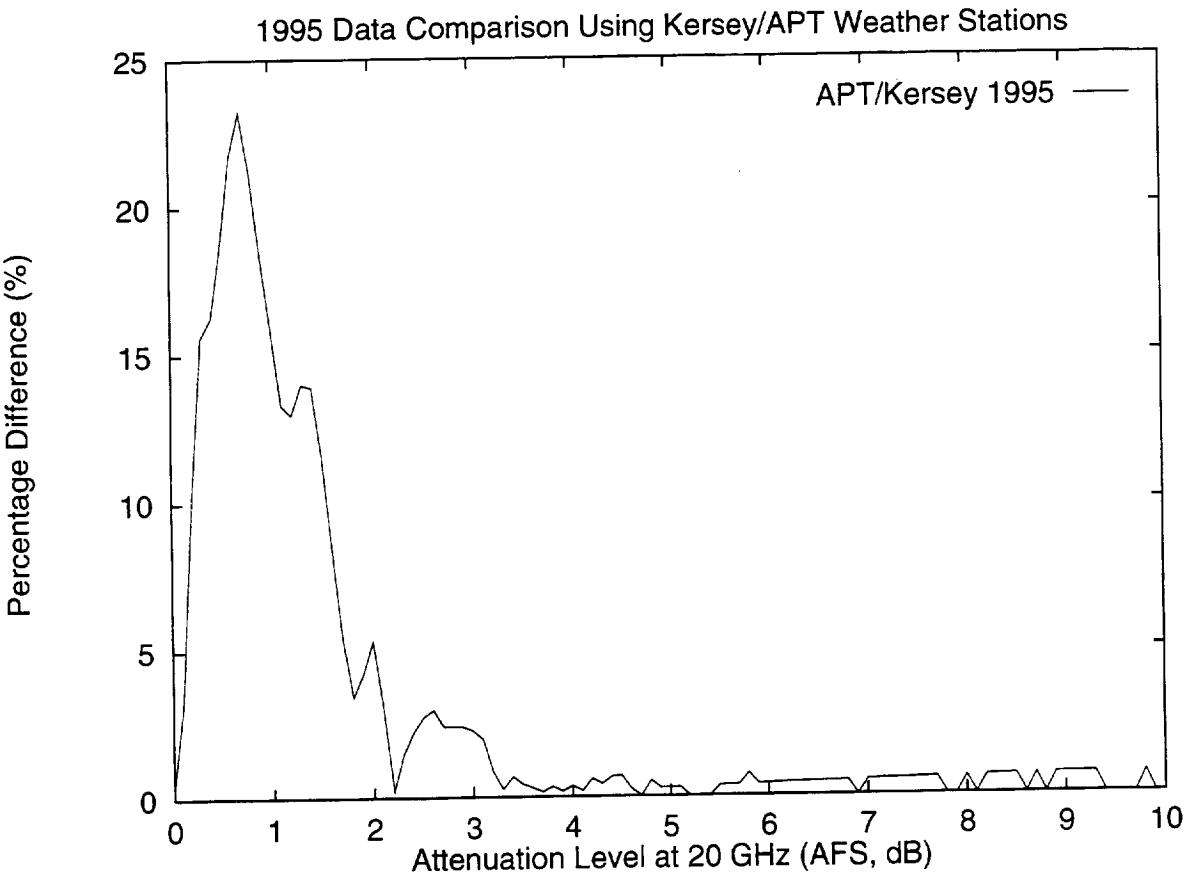

April 1996 Data Comparison Using Various Weather Stations
APT Surface Data
CoAg Surface Data (Ault)
CoAg Surface Data (Kersey)
Percentage Time Attenuation Exceeded (%)
100
10
1
0.1
0.01
0
1
2
3
4
5
6
Attenuation Level at 20 GHz (AFS,dB)


April 1996 Data Comparison Using Various Weather Stations
Percentage Time Attenuation Exceeded (%)
100
90
80
70
60
50
40
30
20
10
0
0
0.25
0.5
0.75
1
Attenuation Level at 20 GHz (AFS,dB)
APT Surface Data
CoAg Surface Data (Ault)
CoAg Surface Data (Kersey)


April 1996 Data Comparison Using Various Weather Stations
APT/Ault
APT/Kersey
Ault/Kersey
Percentage Difference (%)
Attenuation Level at 20 GHz (AFS, dB)
0
10
20
30
40
50
60
70
80
90
100
110
0
1
2
3
4
5
6


April 1996 Data Comparison Using Various Weather Stations
APT/Ault
APT/Kersey
Ault/Kersey
Percentage Difference (%)
Attenuation Level at 27 GHz (AFS, dB)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6


1995 Data Comparison Using Kersey/APT Weather Stations
APT Surface Data
CoAg Surface Data (Kersey)
Percentage Time Attenuation Exceeded (%)
Attenuation Level at 20 GHz (AFS,dB)
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1


1995 Data Comparison Using Kersey/APT Weather Stations
APT/Kersey 1995
Percentage Difference (%)
Attenuation Level at 20 GHz (AFS, dB)
0
5
10
15
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1
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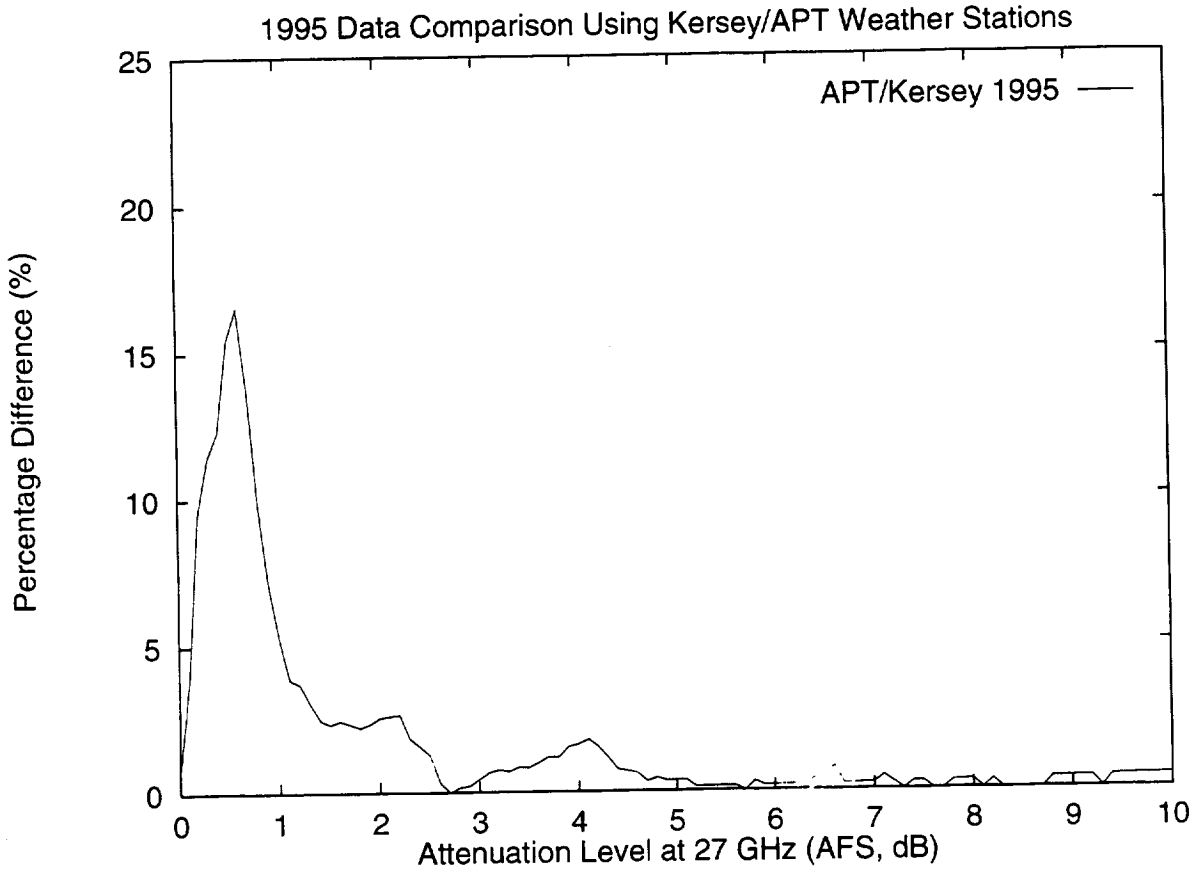
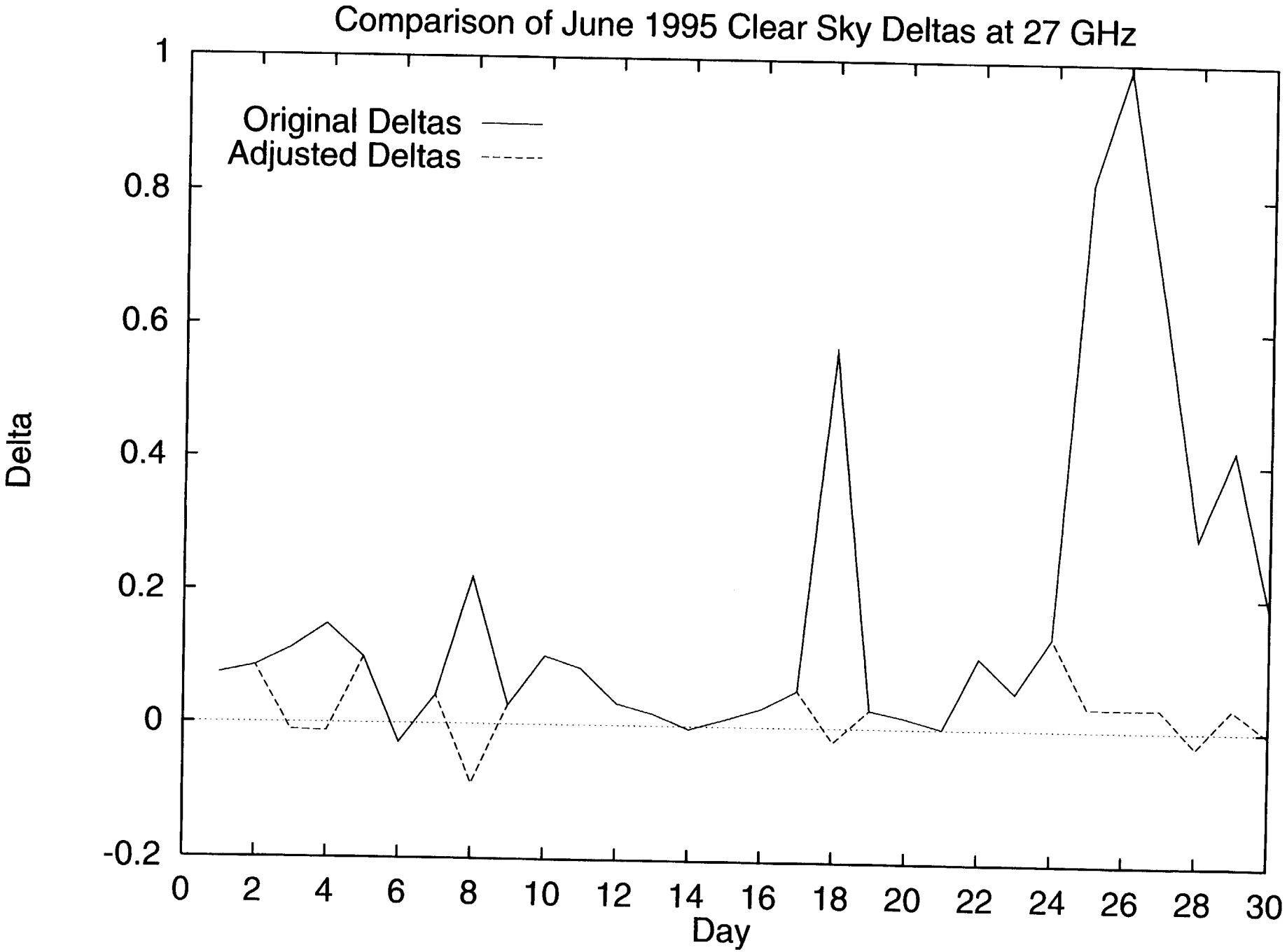
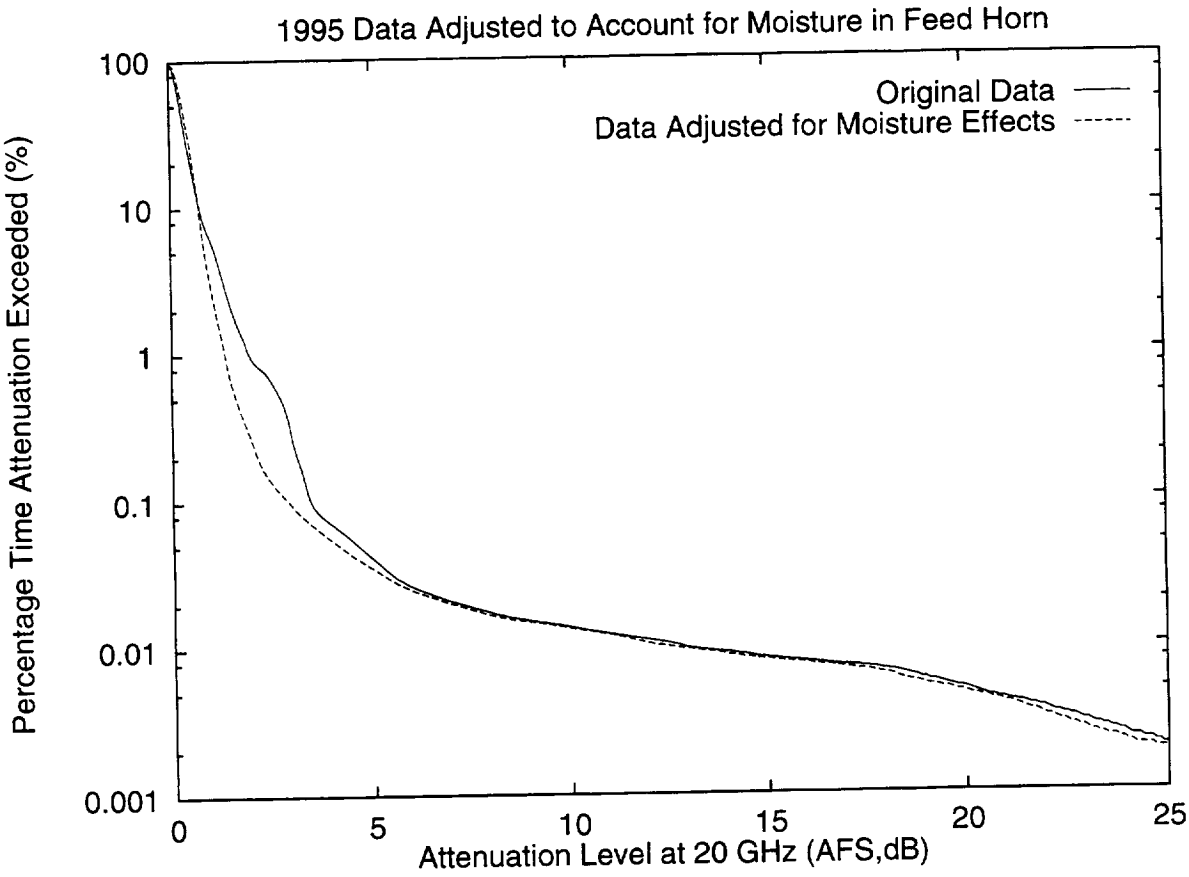
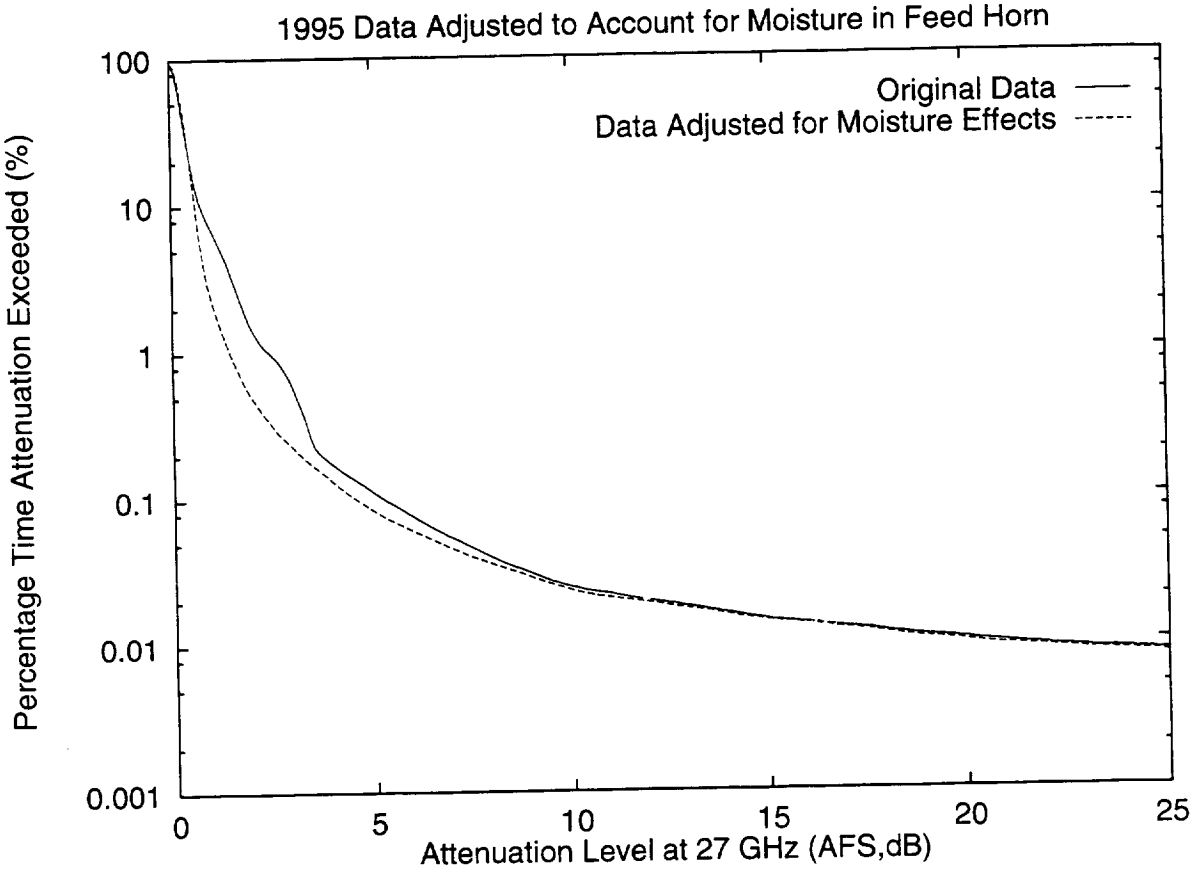
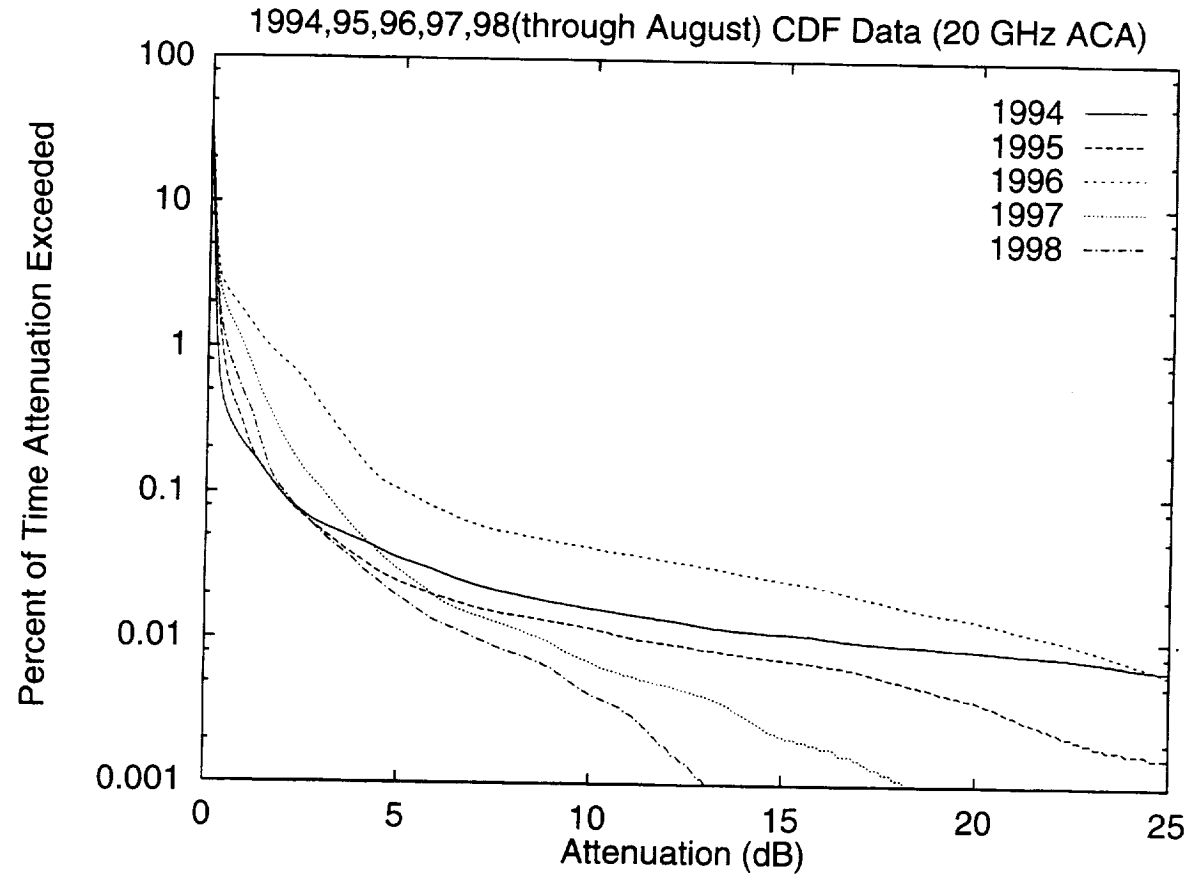
3
4
5
6
7
8
9
10

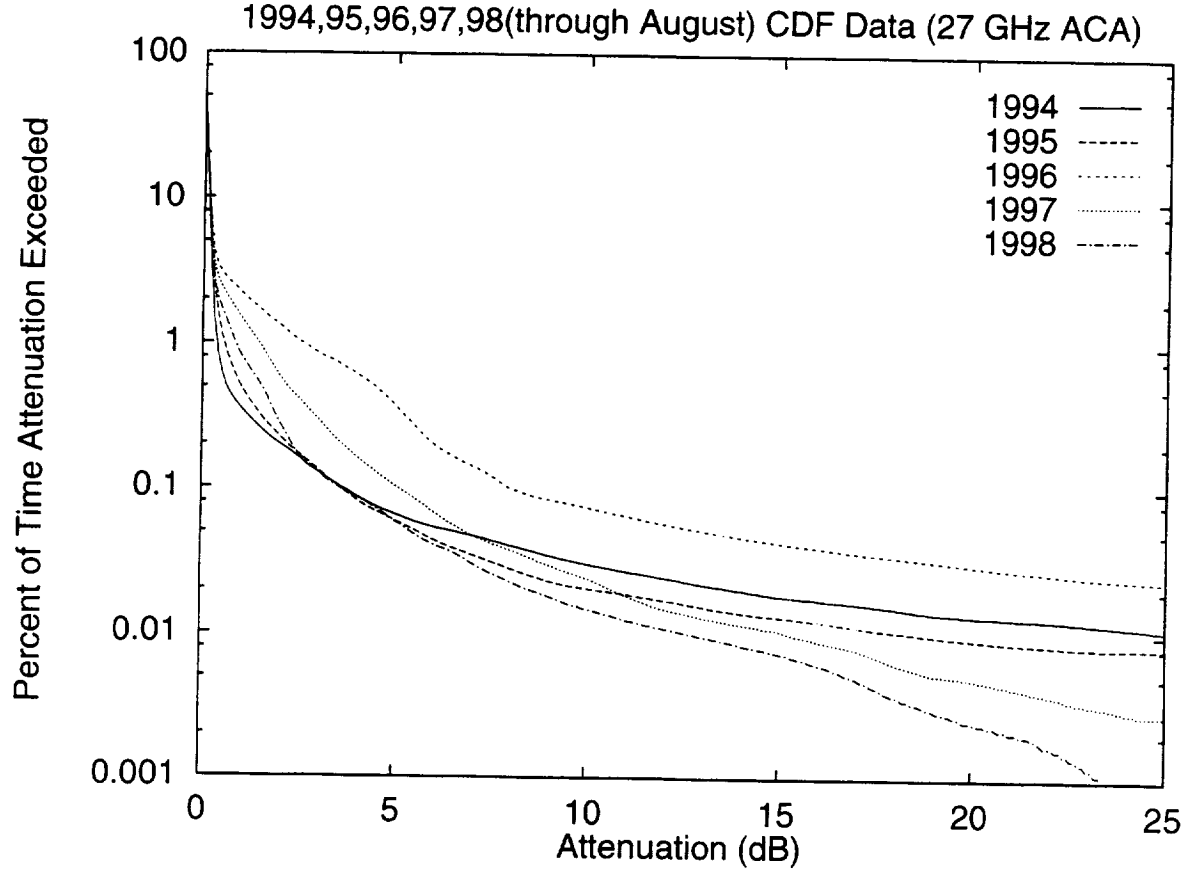

1995 Data Comparison Using Kersey/APT Weather Stations
APT/Kersey 1995
Percentage Difference (%)
Attenuation Level at 27 GHz (AFS, dB)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
8
9
10

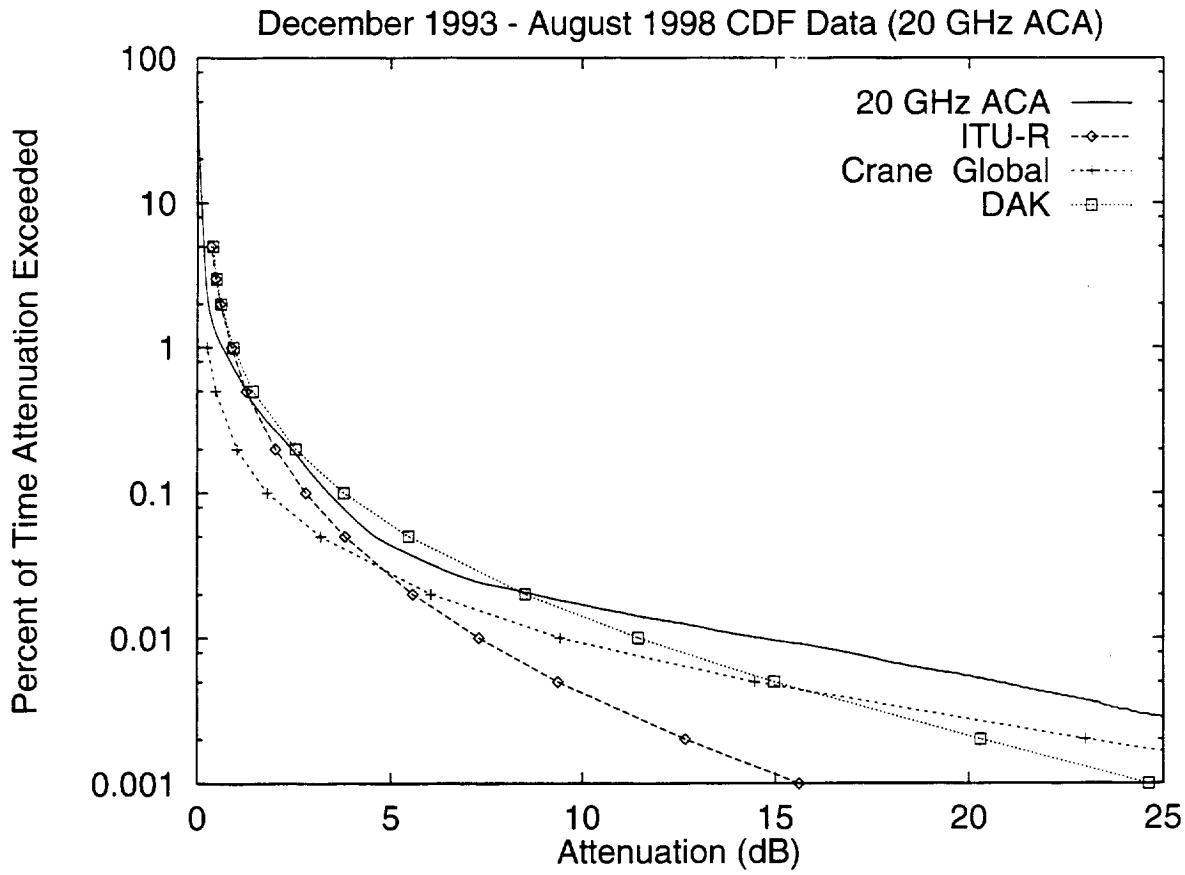

Comparison of June 1995 Clear Sky Deltas at 27 GHz
Original Deltas
Adjusted Deltas
Delta
Day
1
0.8
0.6
0.4
0.2
0
-0.2
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30

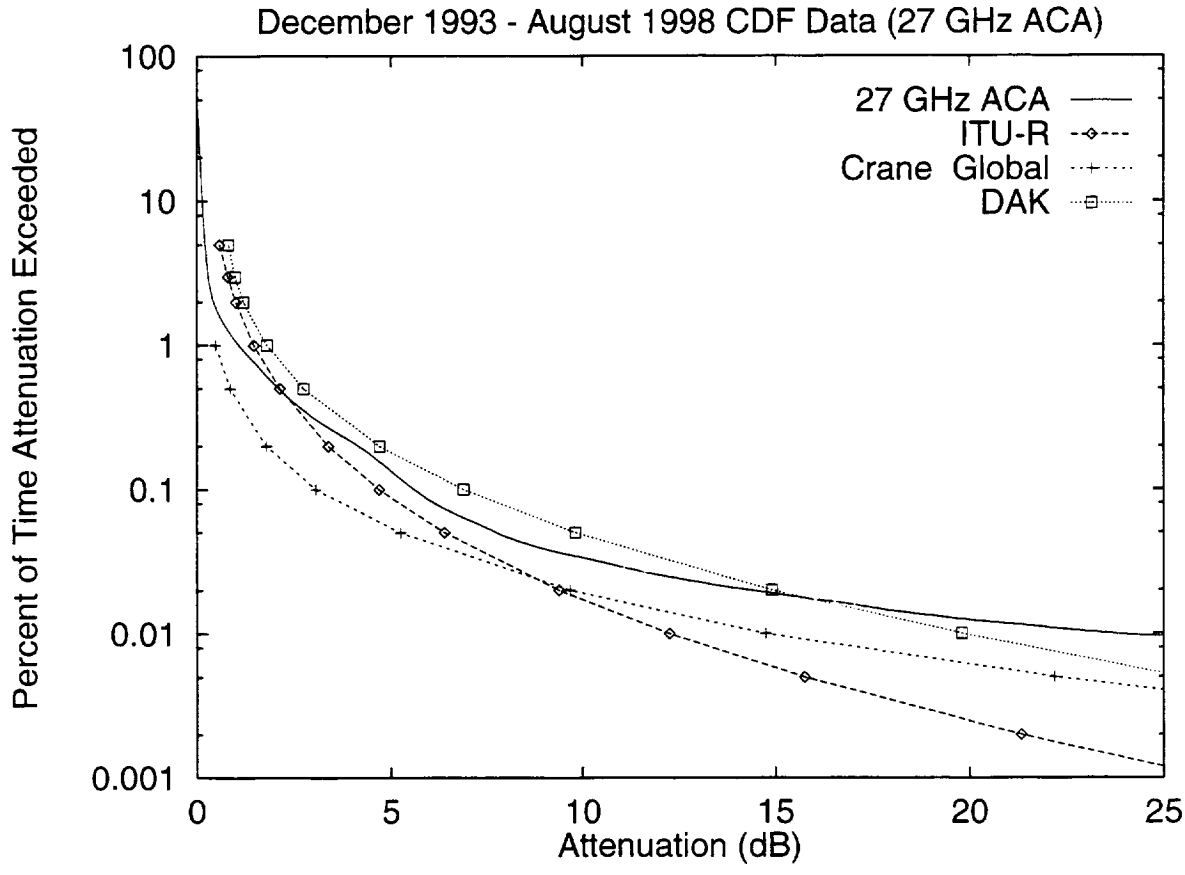

1995 Data Adjusted to Account for Moisture in Feed Horn
Original Data
Data Adjusted for Moisture Effects
Percentage Time Attenuation Exceeded (%)
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation Level at 20 GHz (AFS,dB)

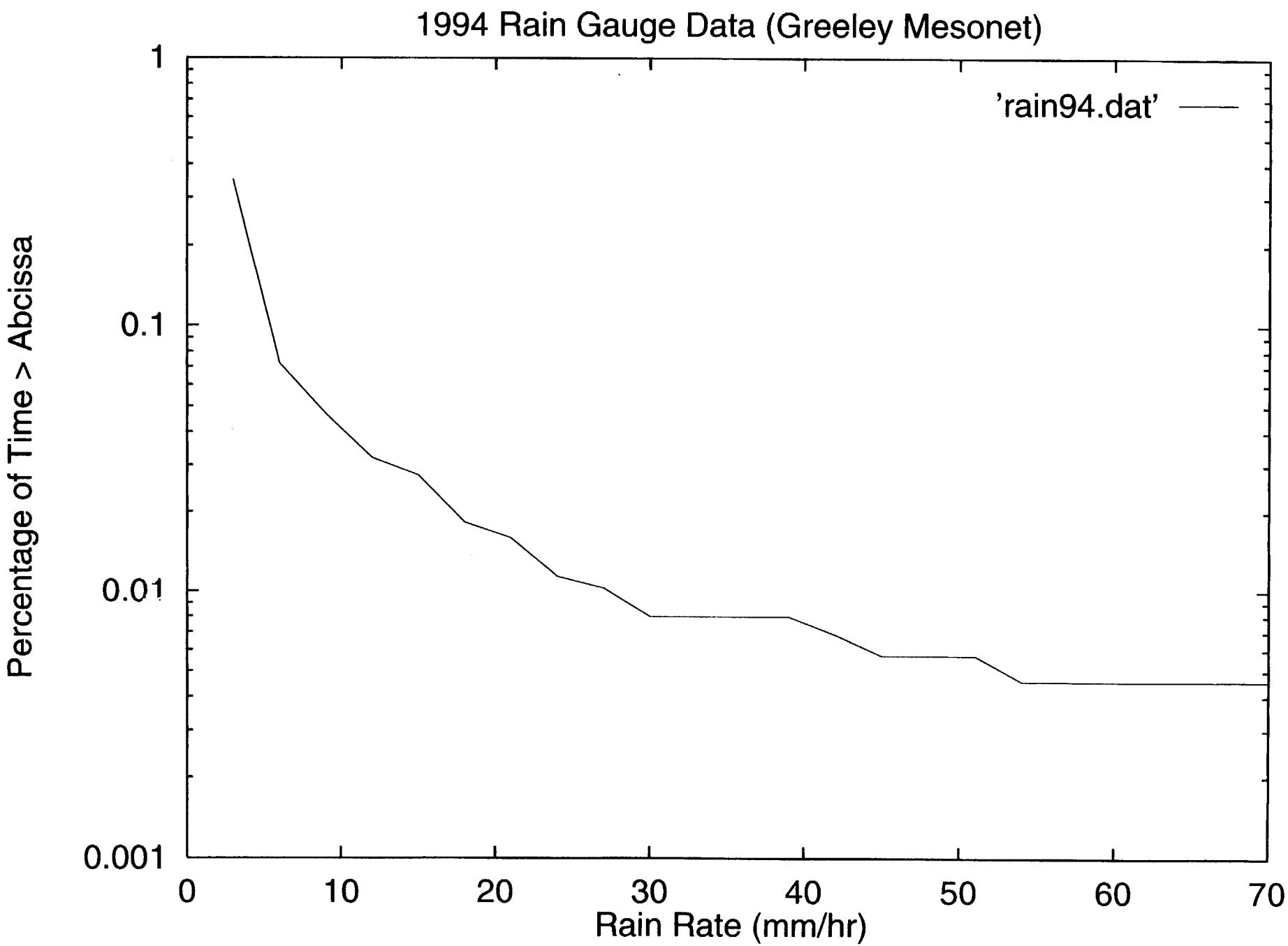

1995 Data Adjusted to Account for Moisture in Feed Horn
Original Data
Data Adjusted for Moisture Effects
Percentage Time Attenuation Exceeded (%)
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation Level at 27 GHz (AFS,dB)

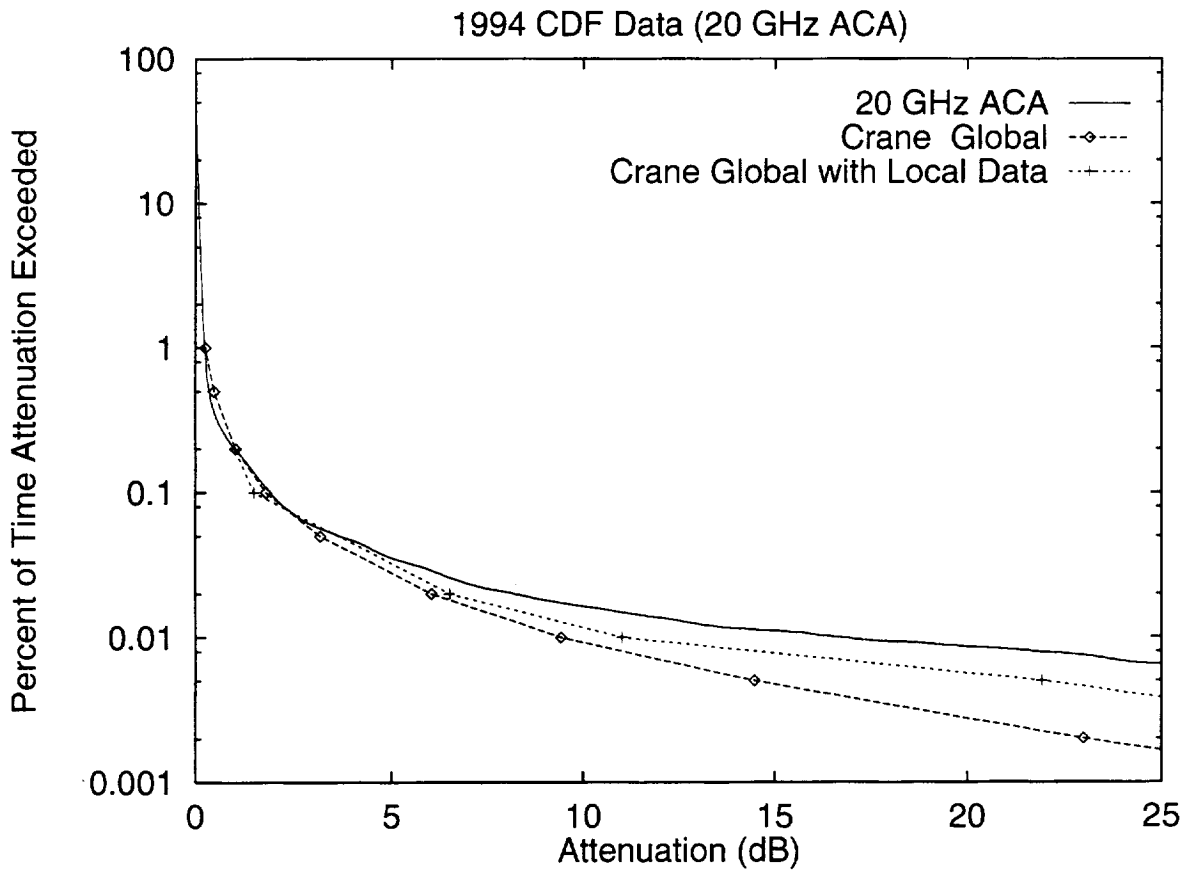

1994,95,96,97,98(through August) CDF Data (20 GHz ACA)
Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation (dB)
1994
1995
1996
1997
1998

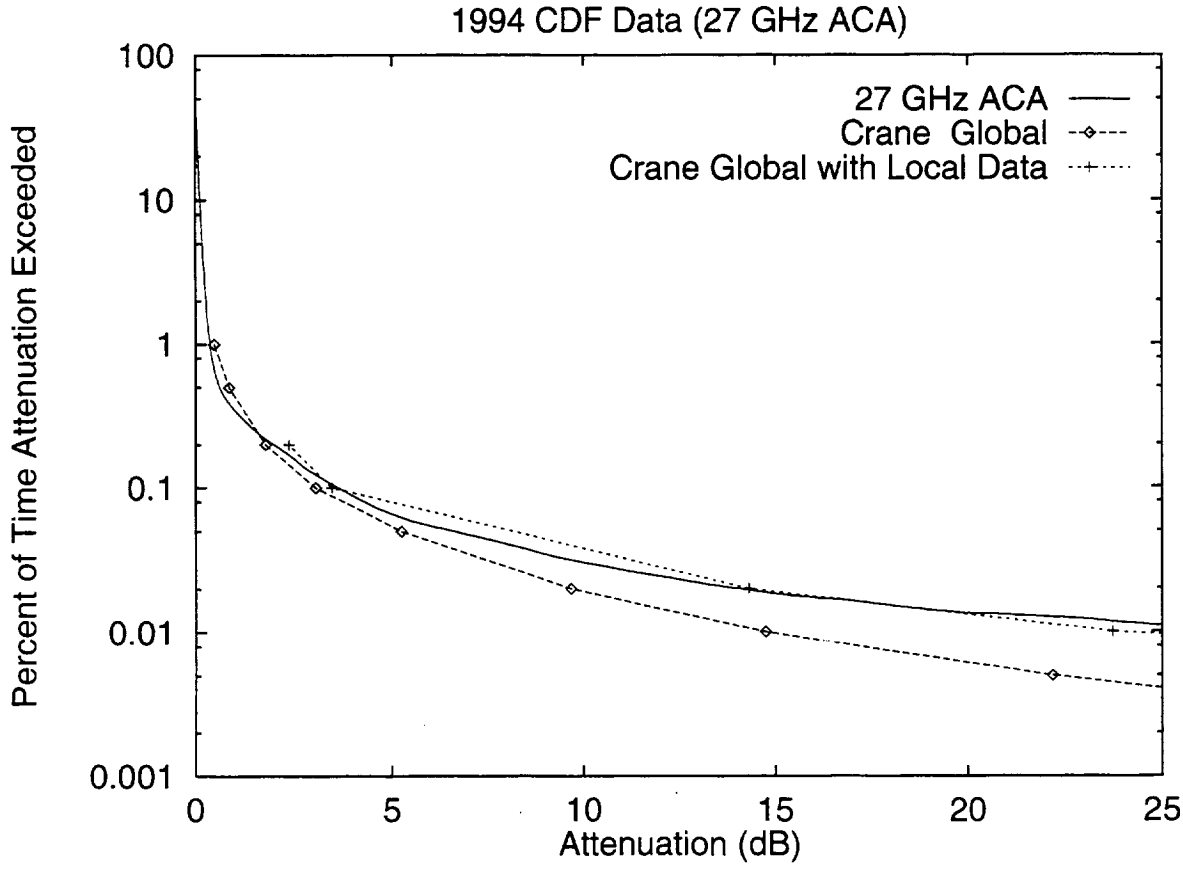

1994,95,96,97,98(through August) CDF Data (27 GHz ACA)
Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation (dB)
1994
1995
1996
1997
1998

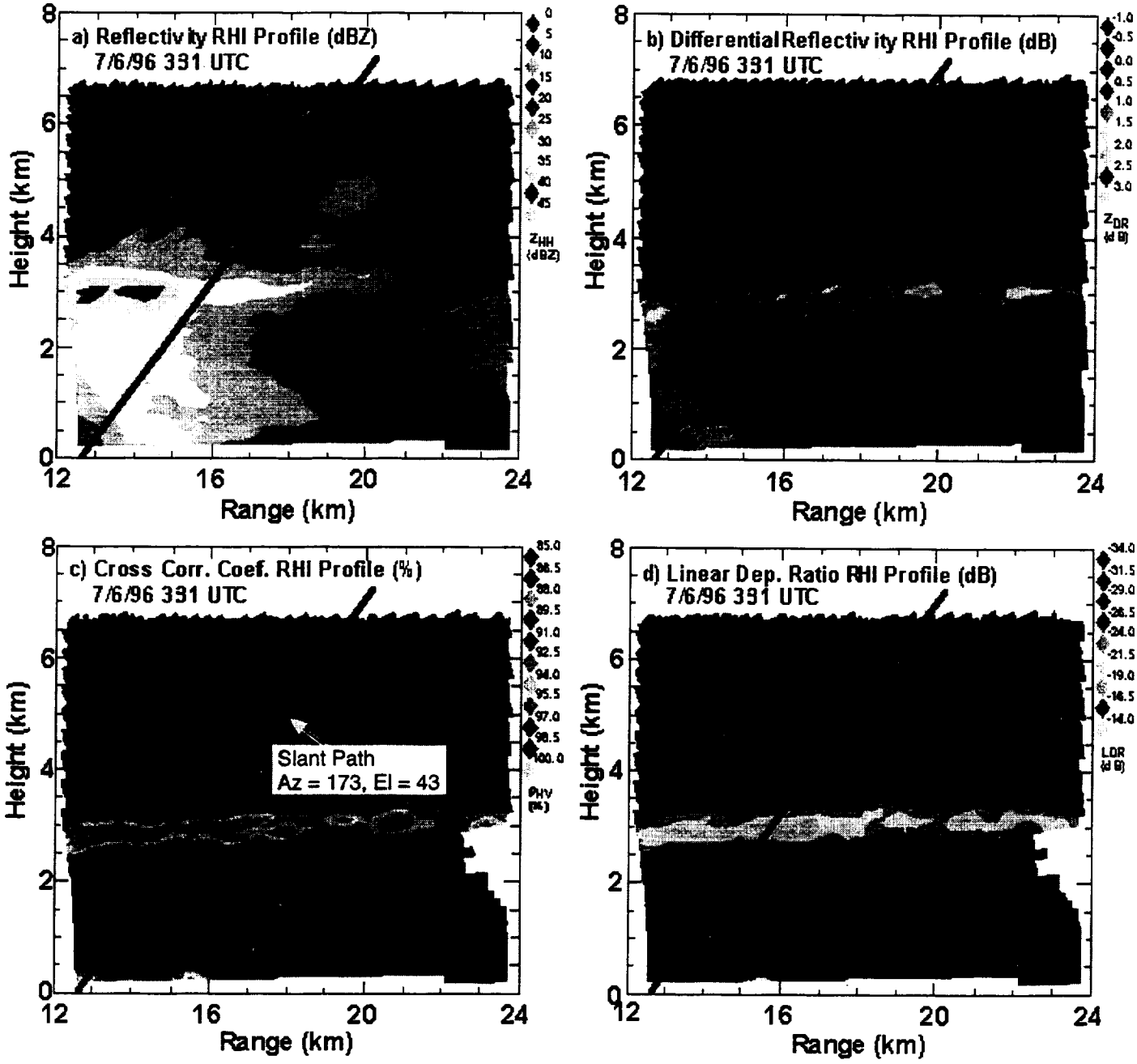

December 1993 - August 1998 CDF Data (20 GHz ACA)
Percent of Time Attenuation Exceeded
Attenuation (dB)
20 GHz ACA
ITU-R
Crane Global
DAK
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25


December 1993 - August 1998 CDF Data (27 GHz ACA)
Percent of Time Attenuation Exceeded
Attenuation (dB)
27 GHz ACA
ITU-R
Crane Global
DAK
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25

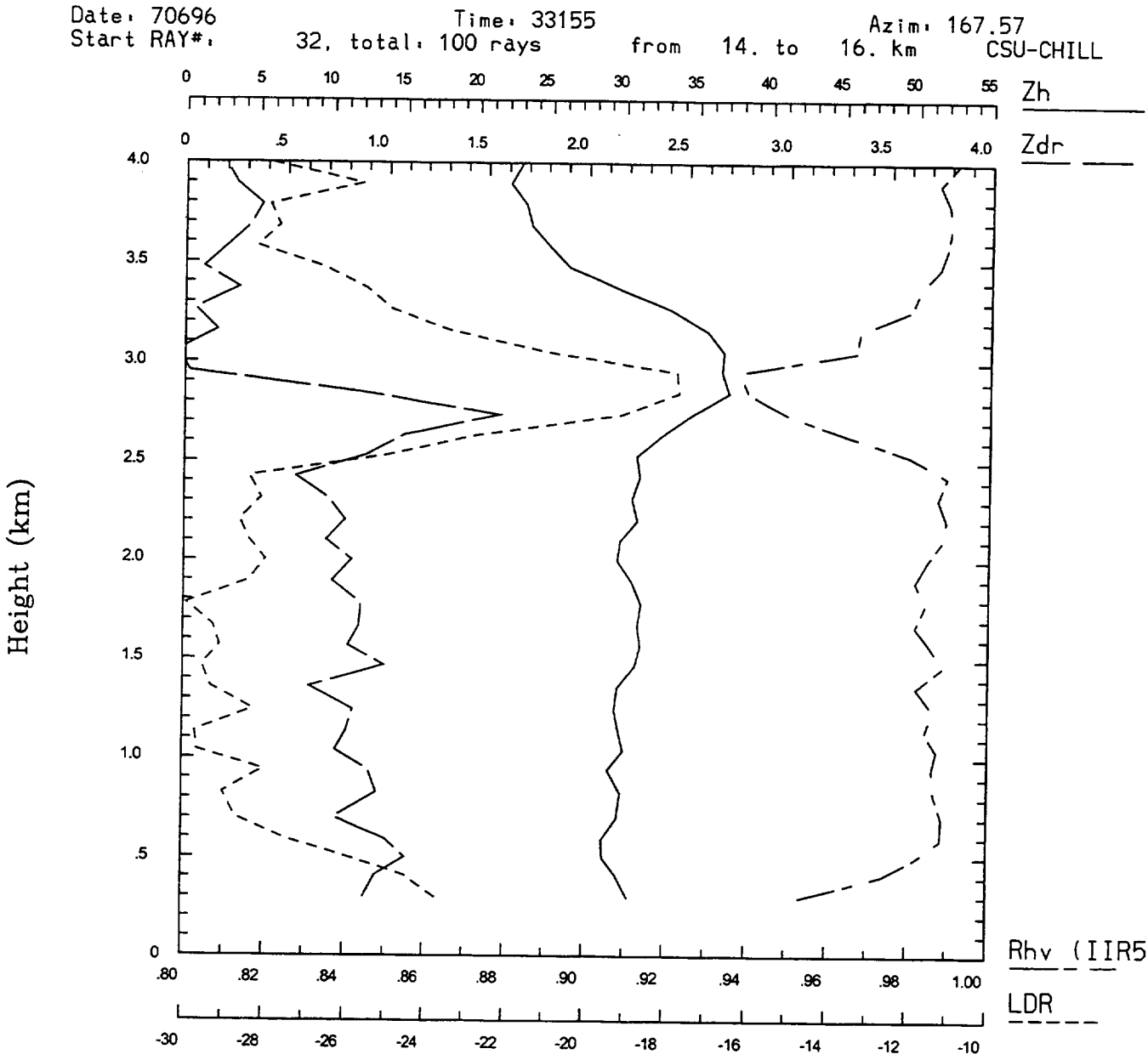

1994 Rain Gauge Data (Greeley Mesonet)
'rain94.dat'
Percentage of Time > Abcissa
1
0.1
0.01
0.001
0
10
20
30
40
50
60
70
Rain Rate (mm/hr)


1994 CDF Data (20 GHz ACA)
Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation (dB)
20 GHz ACA
Crane Global
Crane Global with Local Data


1994 CDF Data (27 GHz ACA)
Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation (dB)
27 GHz ACA
Crane Global
Crane Global with Local Data


a) Reflectivity RHI Profile (dBZ)
7/6/96 331 UTC
b) Differential Reflectivity RHI Profile (dB)
7/6/96 331 UTC
c) Cross Corr. Coef. RHI Profile (%)
7/6/96 331 UTC
Slant Path
Az = 173, El = 43
d) Linear Dep. Ratio RHI Profile (dB)
7/6/96 331 UTC
Height (km)
Range (km)
0
2
4
6
8
12
16
20
24

July 6, 1996 Vertical Profile Plot



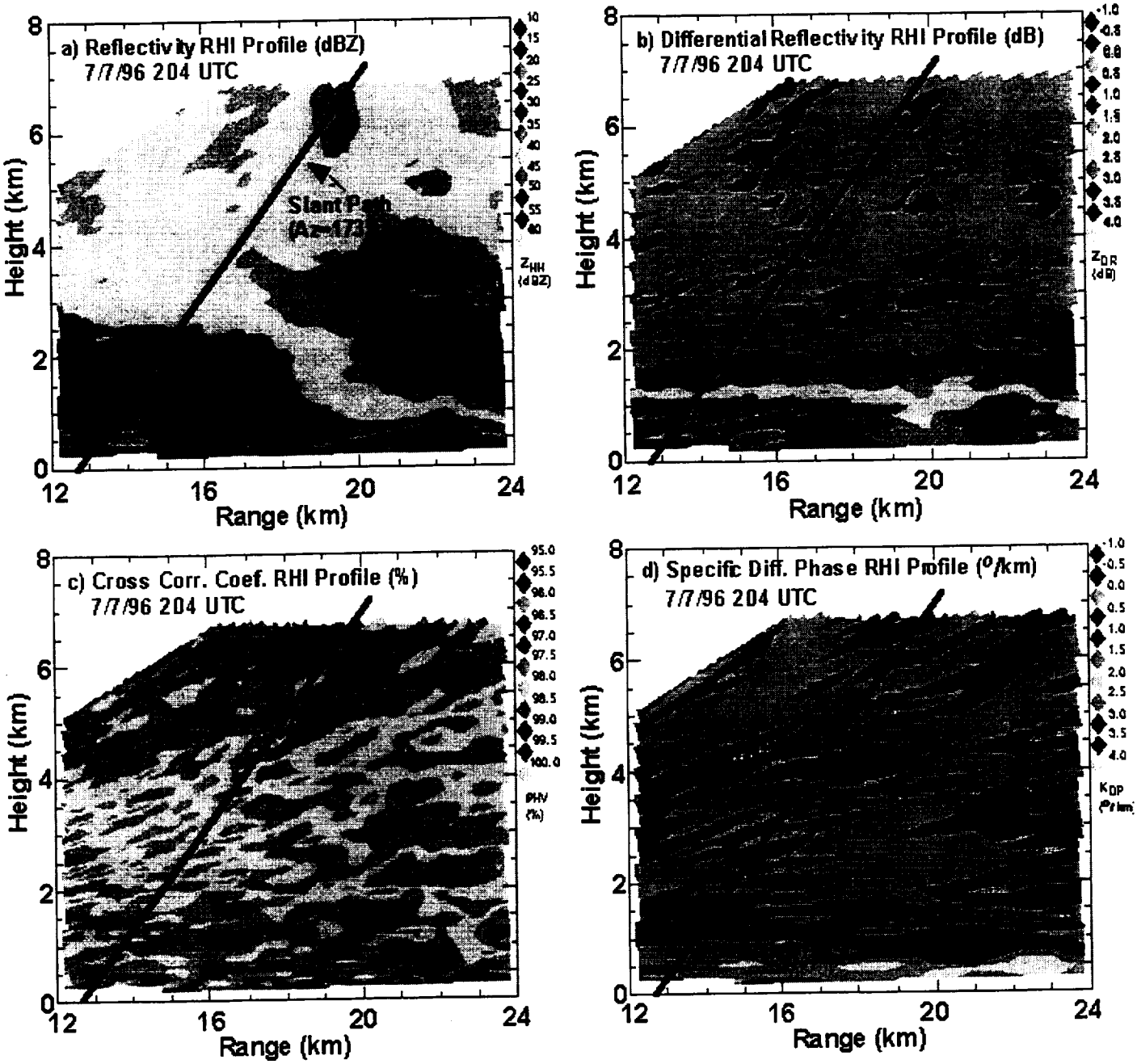
Phidp.T= 3.deg
Dfr.T = 0.dB
Ldr.T = 0.dB

Ro.T= 0.90
Zh.T= 0.dB

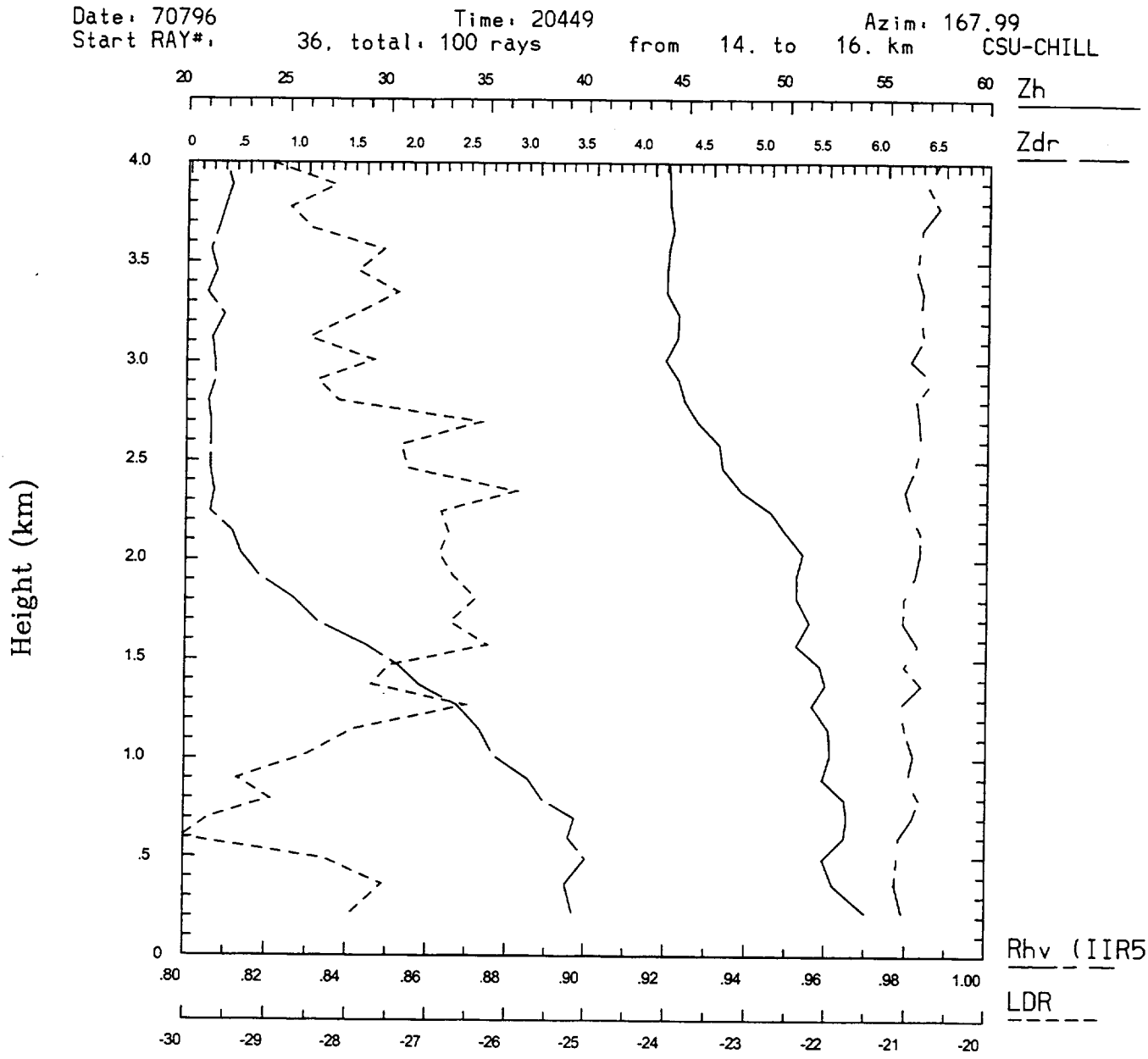
Zslope= 40.dB
Madflt = 2

RCcf= 0.00dB
DfrC= 0.00dB

jul596v262.chl


a) Reflectivity RHI Profile (dBZ)
7/7/96 204 UTC
Slant Path
(Az=173)
Height (km)
Range (km)
b) Differential Reflectivity RHI Profile (dB)
7/7/96 204 UTC
Height (km)
Range (km)
c) Cross Corr. Coef. RHI Profile (%)
7/7/96 204 UTC
Height (km)
Range (km)
d) Specific Diff. Phase RHI Profile (°/km)
7/7/96 204 UTC
Height (km)
Range (km)

July 7, 1996 Vertical Profile Plot



Phidp.T= 3.deg
Dfr.T = 0.dB
Ldr.T = 0.dB

Ro.T= 0.90
Zh.T= 0.dB

Zslope= 40.dB
Madflt = 2

RCcf= 0.00dB
DfrC= 0.00dB

jul696v514.chl

ACTS Propagation Measurements

Asoka Dissanayake, K. T. Lin, and Jorge Sosa

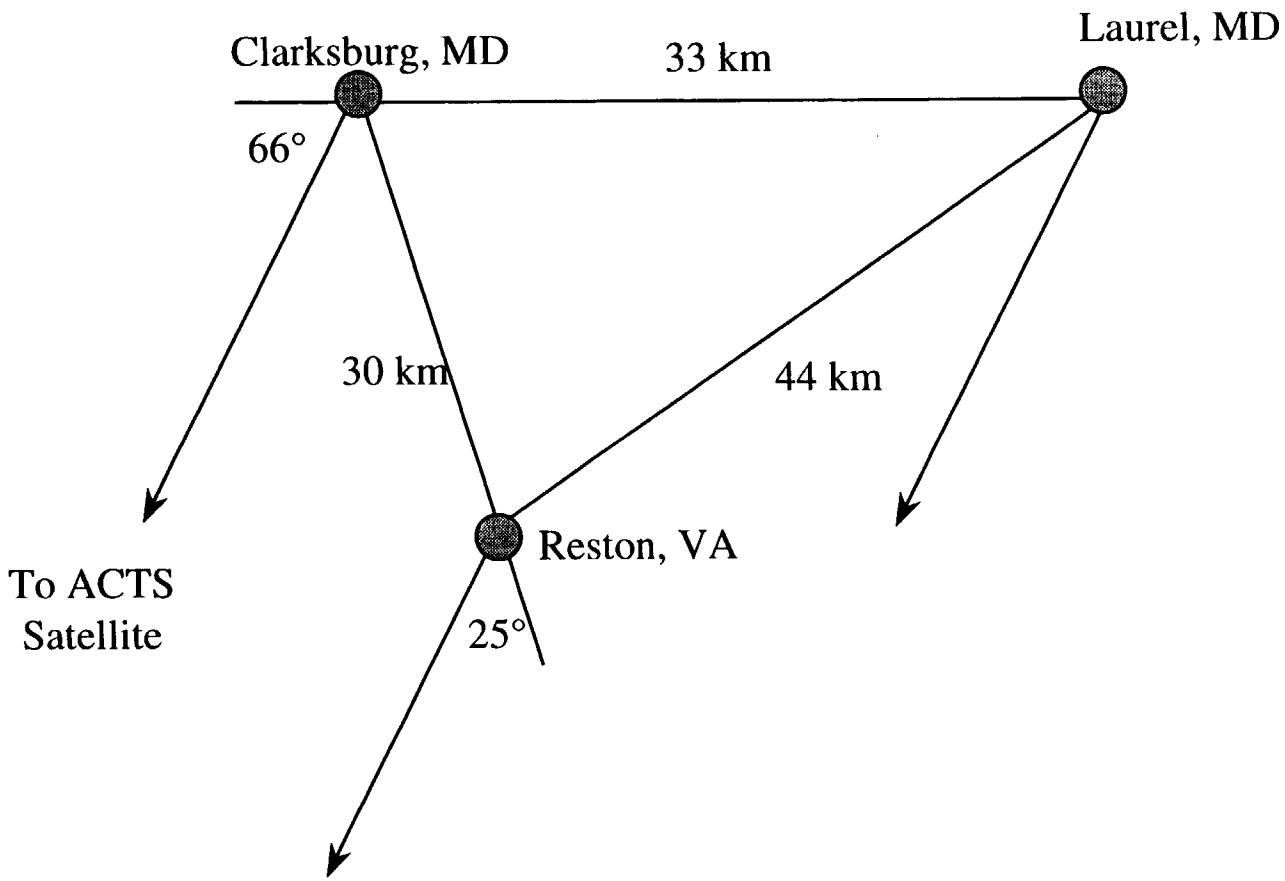
22 October 1998

Introduction

- ACTS propagation measurements conducted at three sites in Washington DC area and a tropical location in Mexico.

- Main objectives of the measurements are:
  - collect long-term propagation data
  - investigate multiple site diversity
  - characterize propagation conditions in tropical areas
  - development of propagation models
  - investigation of fade mitigation techniques

Measurement Site Configuration: Washington DC Area



22 October 1998

Program Status

- Data collection:
  - Clarksburg: 52 months completed
  - Reston: 55 months completed
  - Laurel: 33 months completed

- Data analysis:
  - Clarksburg: 52 months completed
  - Reston: 52 months completed

Attenuation Statistics

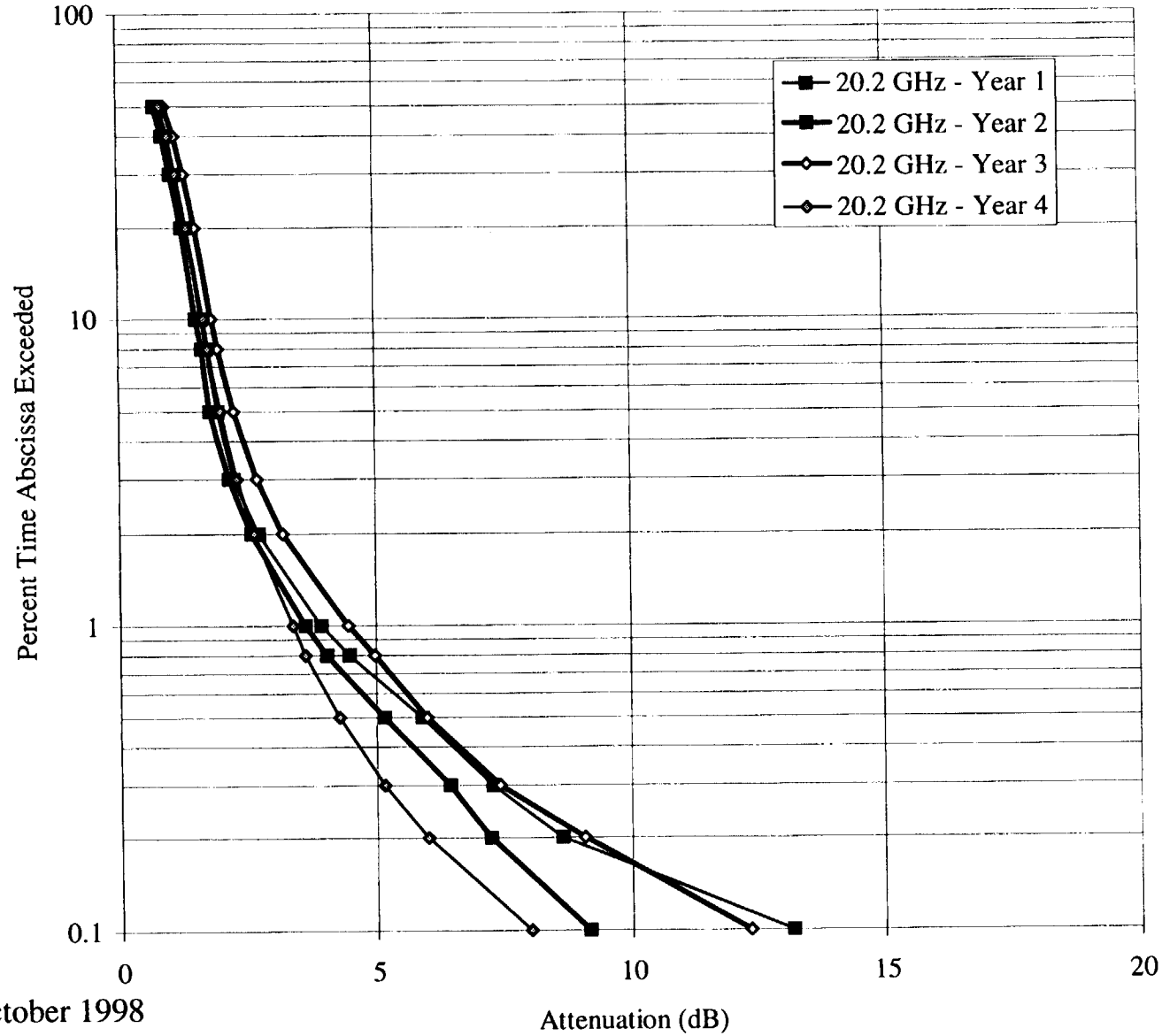
- Single site attenuation statistics for the four years from November 1993 through October 1997 have been generated.

- For the same 12 month period, distribution of attenuation for the two sites are very similar.

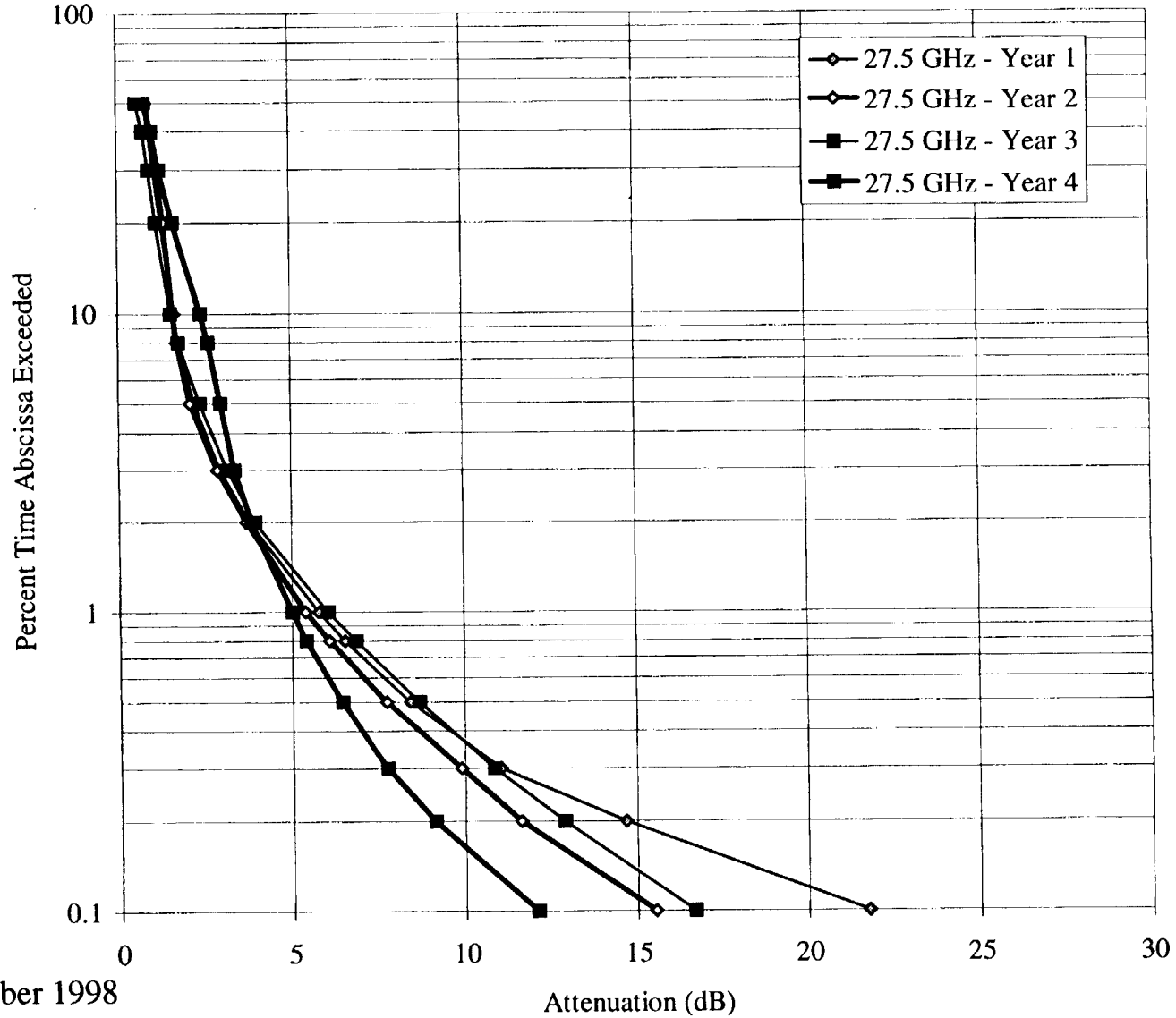
- Considerable year-to-year variability observed in the data.

- Model predictions fall within the annual variation.

Cumulative Distribution of Attenuation at 20.2 GHz: Clarksburg



Cumulative Distribution of Attenuation at 27.5 GHz: Clarksburg



22 October 1998

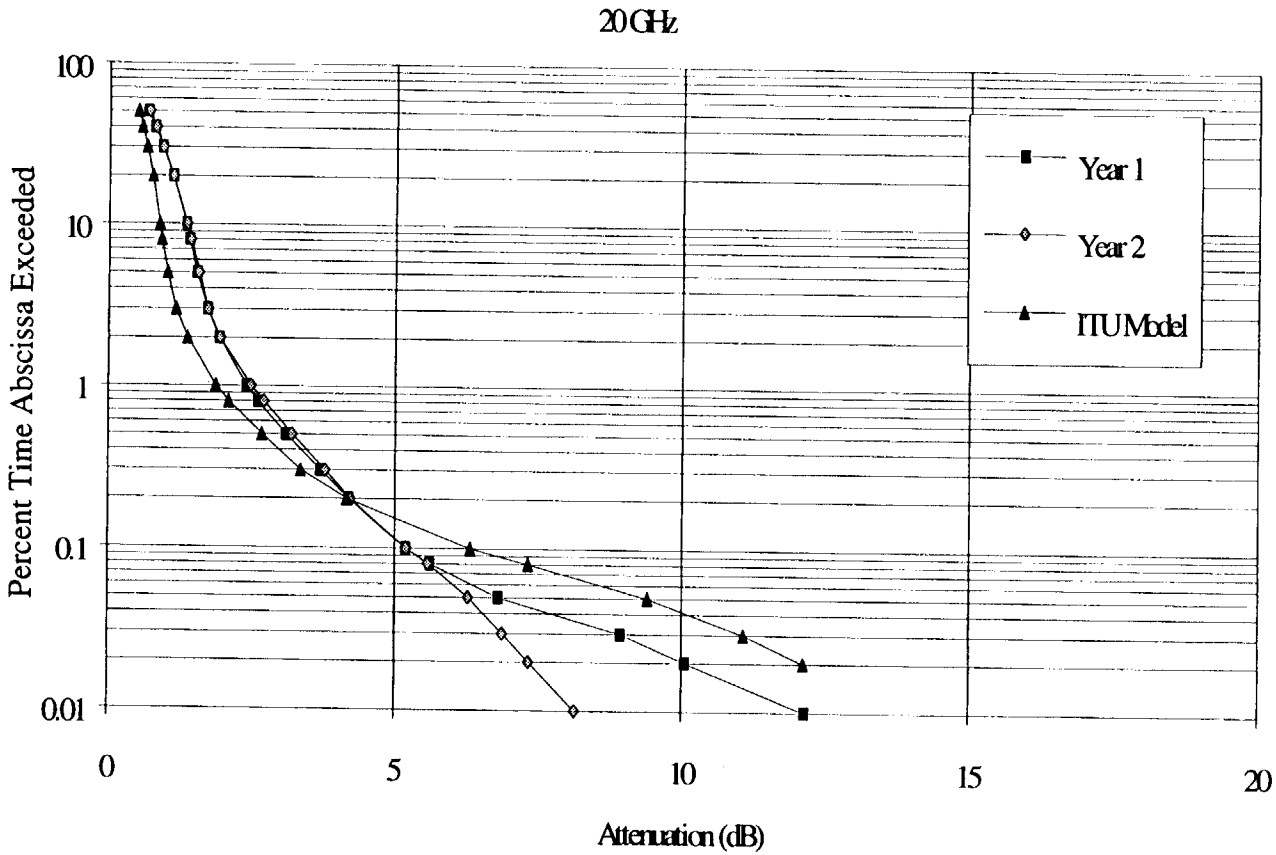
Diversity Analysis

- Diversity statistics derived for the two site configuration Clarksburg and Reston.

- Very little variation between joint statistics for the first two measurement years.

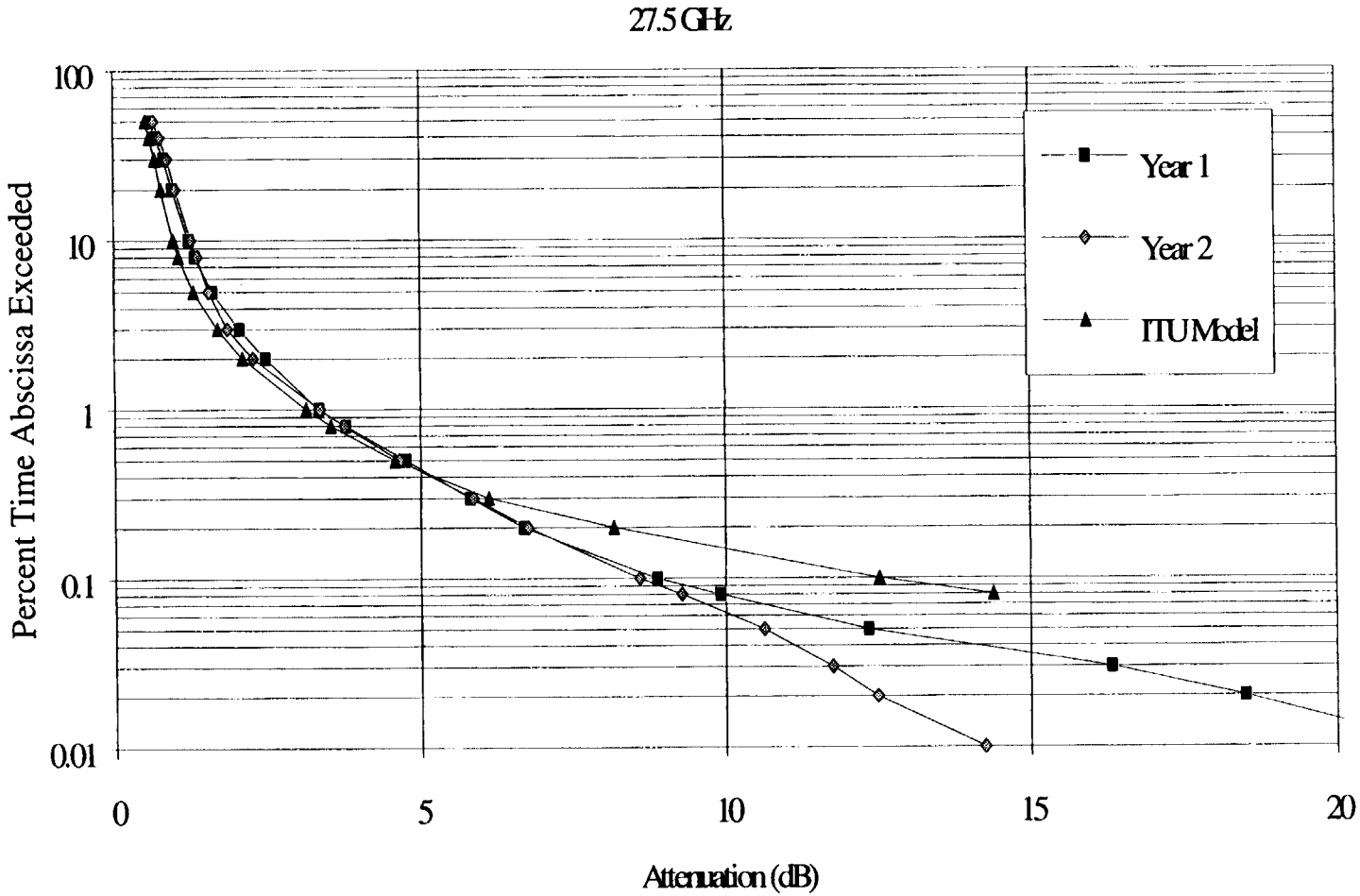
- ITU Diversity prediction model appears to under estimate diversity gain for percentage times greater than about 99.8%.

Joint Attenuation Statistics at 20.2 GHz



22 October 1998

Joint Attenuation Statistics at 27.5 GHz



Joint Attenuation Between Two Paths

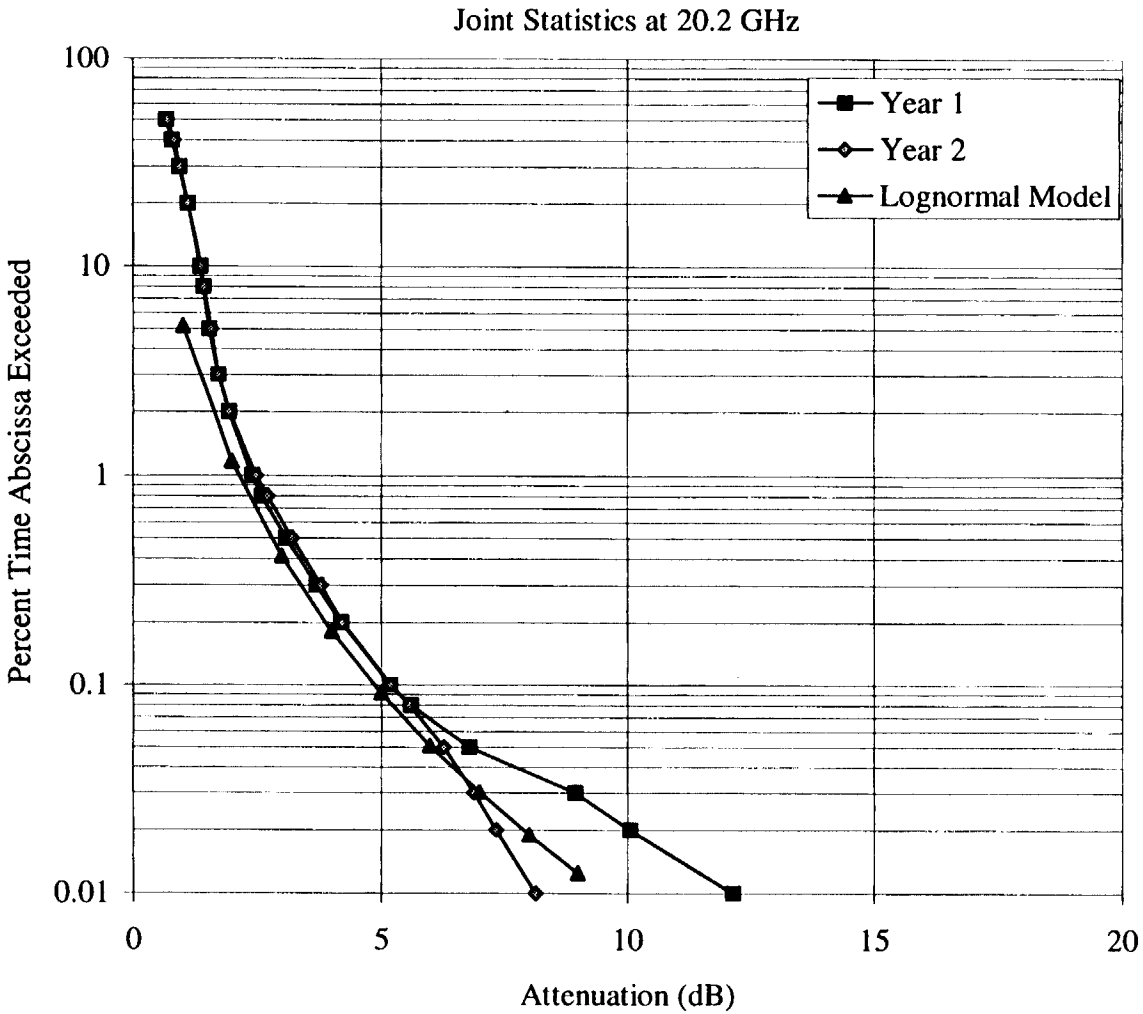
- Modeling of joint attenuation between two paths required in diversity and interference calculations.
- Models based on lognormal statistics are commonly used. The joint probability density function can be expressed as:

$$f(A_a,A_b)= \frac{1}{2\pi\sigma_a\sigma_b A_a A_b \sqrt{1-c^2}} \exp\left(-\frac{1}{2(1-c^2)}\left[\frac{(\ln A_a-\ln \mu_a)^2}{\sigma_a^2} - 2c\frac{(\ln A_a-\ln \mu_a)(\ln A_b-\ln \mu_b)}{\sigma_a\sigma_b} + \frac{(\ln A_b-\ln \mu_b)^2}{\sigma_b^2}\right]\right)$$

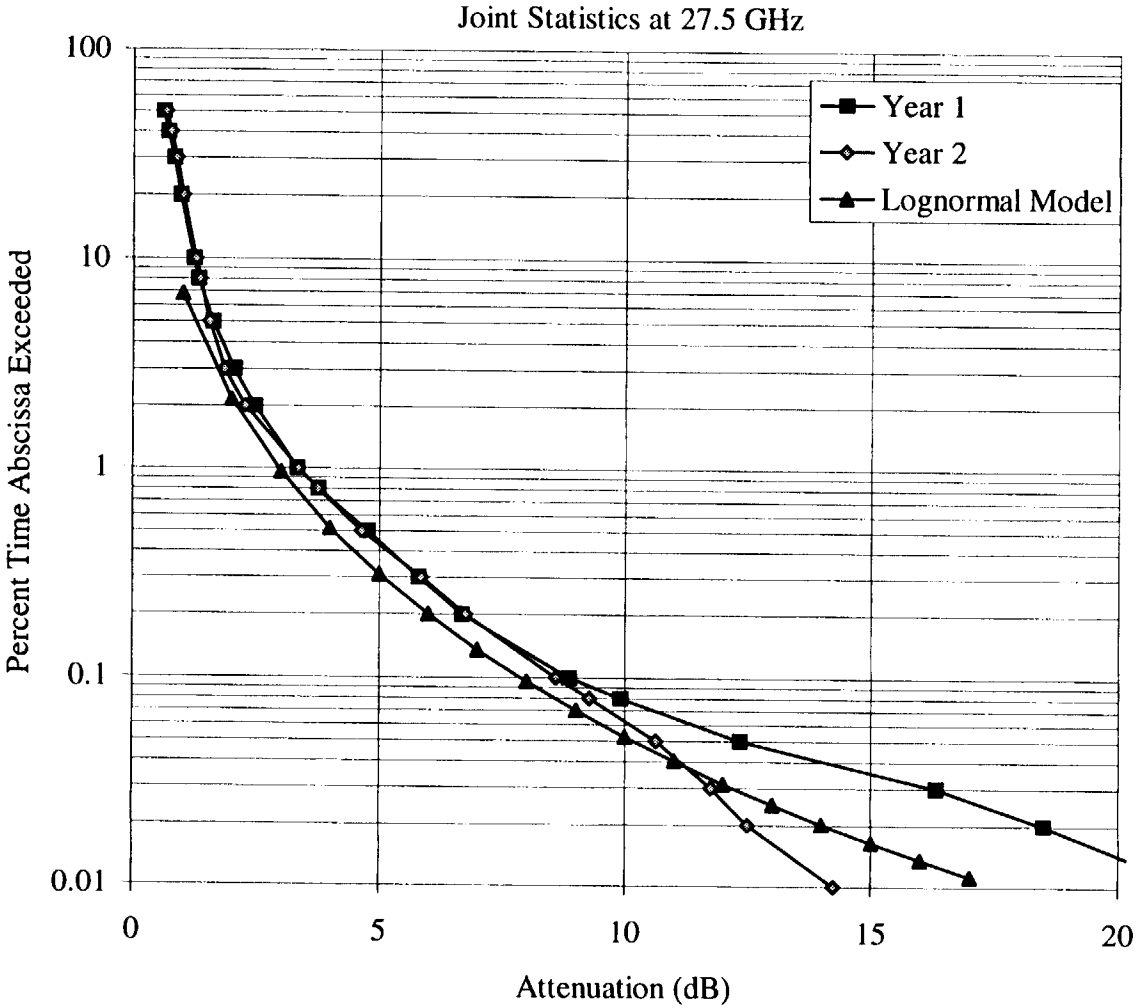
where μ and σ are the mean and the standard deviation of the lognormal distribution, c is the correlation coefficient that depends on the spatial correlation function of rain intensity.

- The correlation function for rain intensity has an exponential form given by: $e^{-\alpha\sqrt{d}}$, where α=0.25 and d is distance km.

Lognormal Diversity Model: 20.2 GHz



Lognormal Diversity Model: 27.5 GHz



22 October 1998

Tropical Propagation Measurements

- Sponsored by INTELSAT
- Measurements conducted in collaboration with IPN, Mexico City.
- Objectives:
  - Collect long-term Ka-band propagation data from a tropical location using ACTS beacon signals.
  - Measurement site: Villahermosa in southern Mexico (latitude: 18° N; annual rain accumulation > 2000 mm)
  - Use of a weather radar to monitor precipitation cells influencing the beacon signals and characterize path attenuation at several elevation angles that are representative inter-continental satellite links.
  - Evaluate and refine propagation models for tropical climates.
  - Investigate frequency scaling within Ka-band and between Ka- and Ku-band.
- Measurements started in September 1998.

Measurement Site

- City: Villa Hermosa (17° 59'N, 92° 55' W, altitude: 10 m)

- Facility owned by Mexican Telecommunications Authority; houses the regional telecommunication monitoring center.

- Annual average rainfall ~ 2000 mm

- Thunderstorm factor ~0.7

- Average temperature 28°C

Mexicali
Tijuana
Ensenada
Nogales
Ciudad Juarez
United States
110
100
90
30
20
Golfo de California
Yaqui
Rio Grande
Hermosillo
Guaymas
Chihuahua
Piedras Negras
Nuevo Laredo
Ciudad Obregon
Hidalgo del Parral
Monclova
Gulf of Mexico
Torreon
Matamoros
Los Mochis
Culiacan
Saltillo
Monterrey
Measurement site
Durango
La Paz
Ciudad Victoria
San Lucas
Mazatlan
Zacatecas
San Luis Potosi
Aguascalientes
Tampico
Bahia de Campeche
Lerma
Tepic
Leon
Merida
Cancun
Irapuato
Queretaro
Poza Rica de Hidalgo
Guadalajara
Salamanca
Pachuca
Campeche
Pacific Ocean
Morelia
Mexico (City)
Manzanillo
Apatzingan
Toluca
Puebla
Veracruz
Cuernavaca
Orizaba
Cordoba
Chetumal
Coatzacoalcos
Balsas
Villahermosa
Minatitlan
Belize
Acapulco
Oaxaca
Tuxtla Gutierrez
Salina Cruz
Guatemala
Hondur.
Mexico
500 km
500 miles
El Salvador
Nicaragua

Tropical Propagation Measurement System

- 2.4m tracking antenna used to monitor 20.2 and 27.5 GHz beacon signals to accommodate inclined orbit operation of ACTS.

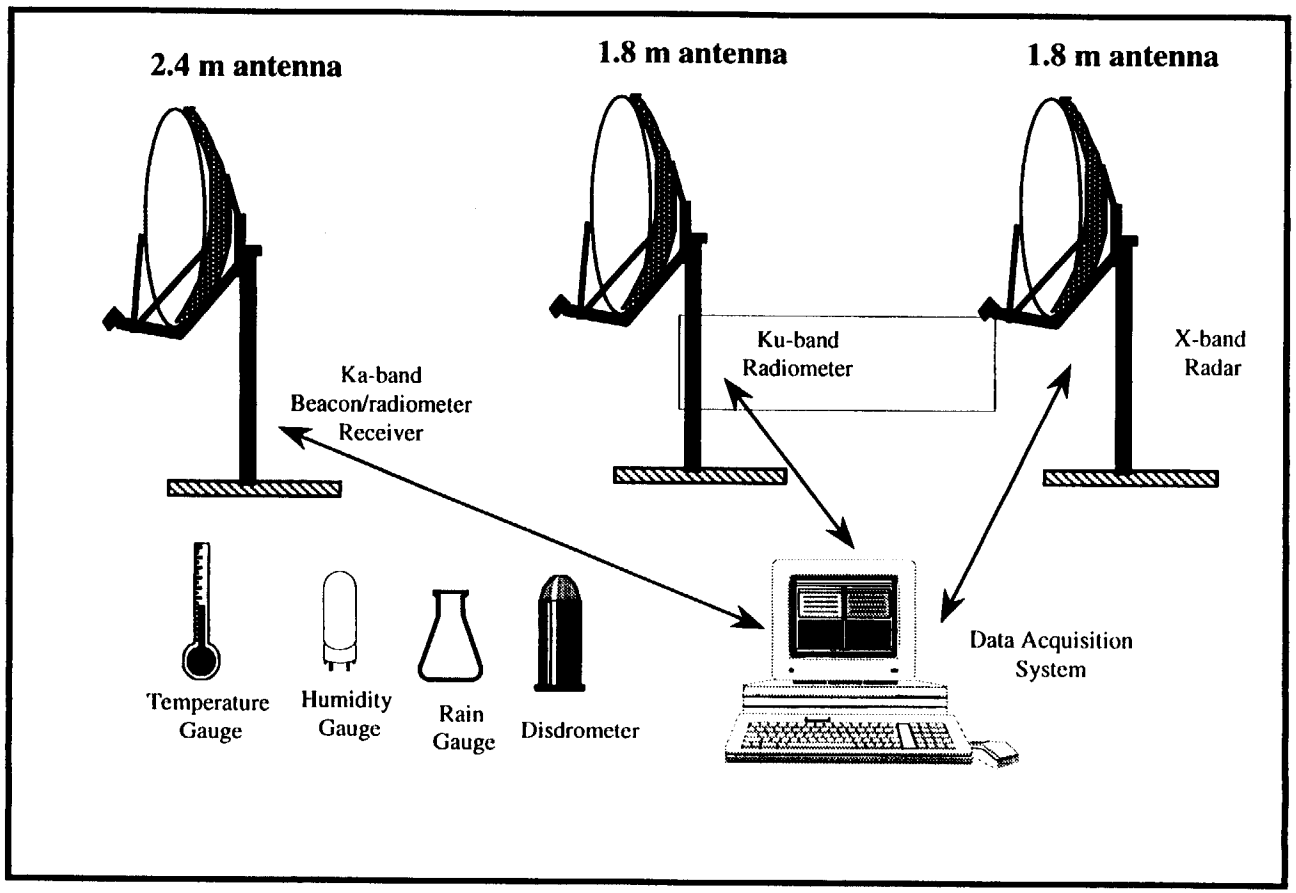
- Radiometers at the beacon frequencies are used to remove equipment and satellite induced variations in the beacon signal level.

- Use of a co-located dual polarized X-band weather radar to estimate path attenuation at elevation angles other than the ACTS elevation.

- Ku-band radiometer to investigate frequency scaling from Ku- to Ka-band.

- Ancillary weather instruments to support data analysis and interpretation (rain gauge, distrometer, humidity gauge, temperature sensor).

Measurement System

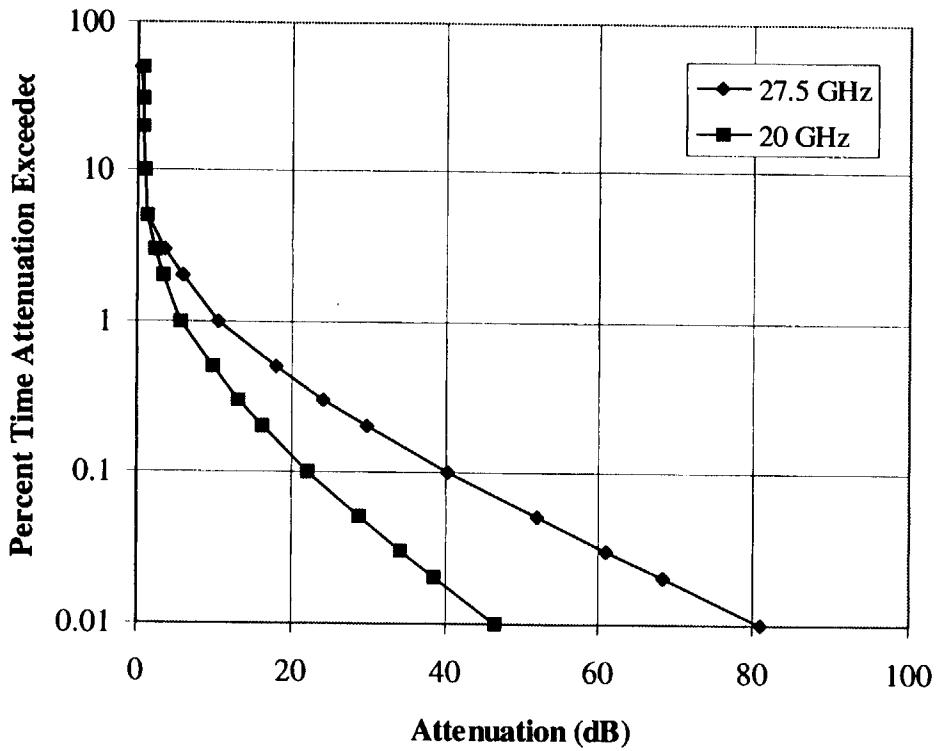


Beacon/Radiometer Receivers

Specifications:

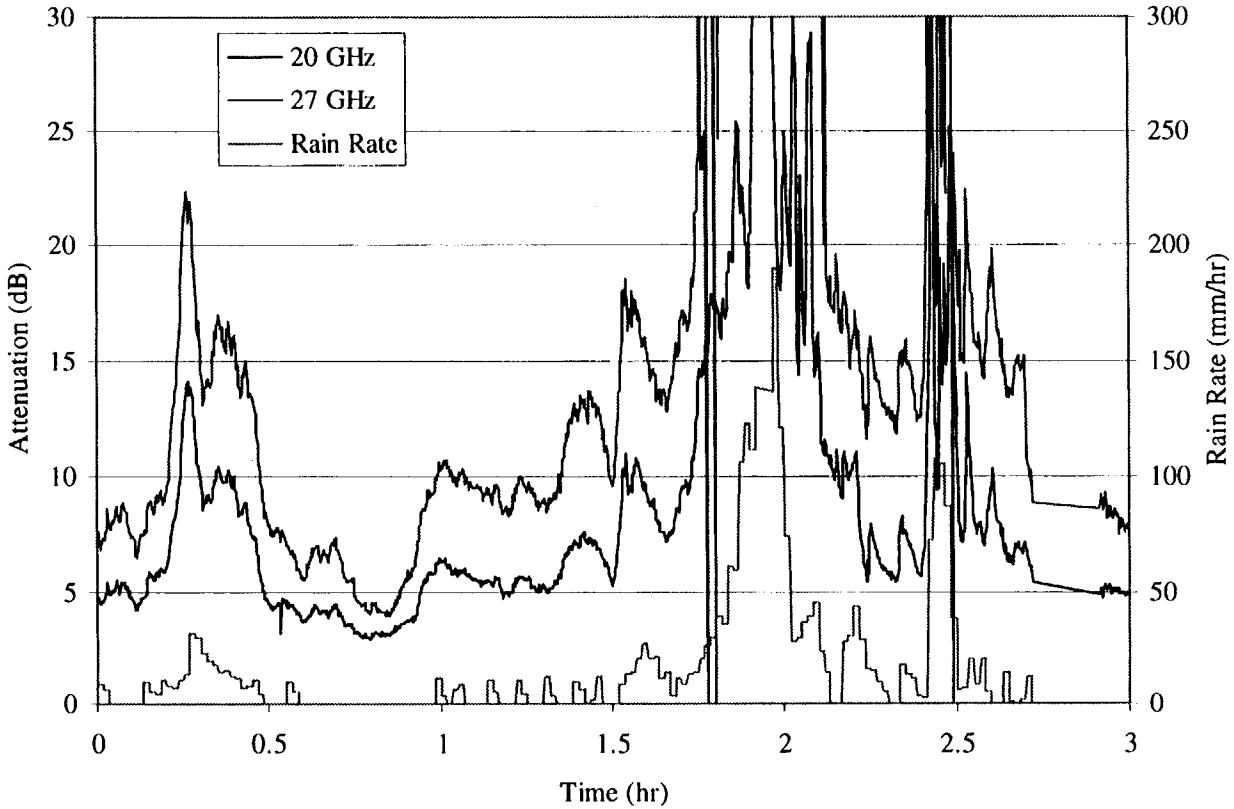
- RF head temperature stabilization < 2° C
- measurement accuracy -
  - beacon signals: < 0.25 dB
  - sky noise: < 2 K
- beacon measurement dynamic range: ~ 30 dB for 20 GHz
  ~ 22 dB for 27 GHz
- signal acquisition after loss of lock: < 20 s
- antenna pointing -
  - step size: ~0.01°
  - update rate: once every 15 minutes

Predicted Attenuation Distribution at Villahermosa



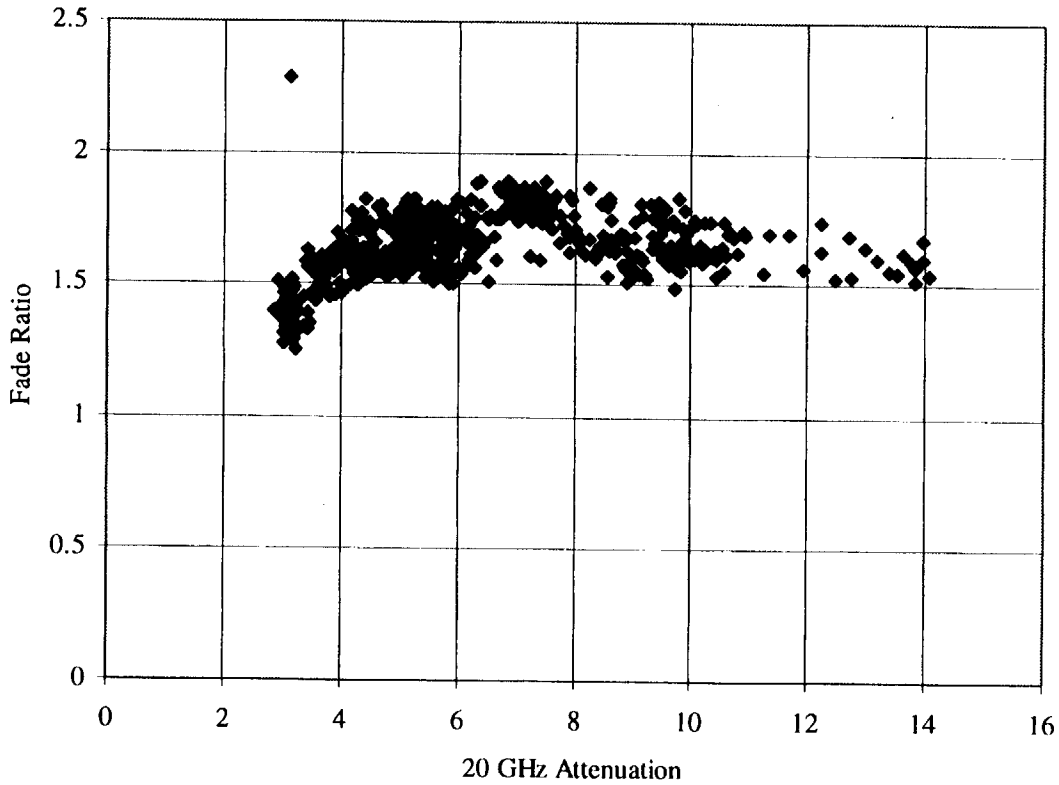
22 October 1998

Rain Event on October 10, 1998



22 October 1998

Fade Ratio Between 27 and 20 GHz



22 October 1998

Conclusions

- ACTS beacon data from Maryland and Virginia used to derive long-term statistics of attenuation.

- Fifth year of data collection in progress in Virginia

- Propagation measurements in Mexico to help characterize tropical conditions.

- Weather radar used to investigate elevation angle scaling of rain attenuation in tropics.

- Data analysis in progress to validate/improve propagation models.

Space Communications Technology Center
(SCTC)

PROPAGATION MEASUREMENTS IN FLORIDA

HENRY HELMKEN
FLORIDA ATLANTIC UNIVERITY (FAU)
&
RUDY HENNING
UNIVERSITY OF SOUTH FLORIDA (USF)

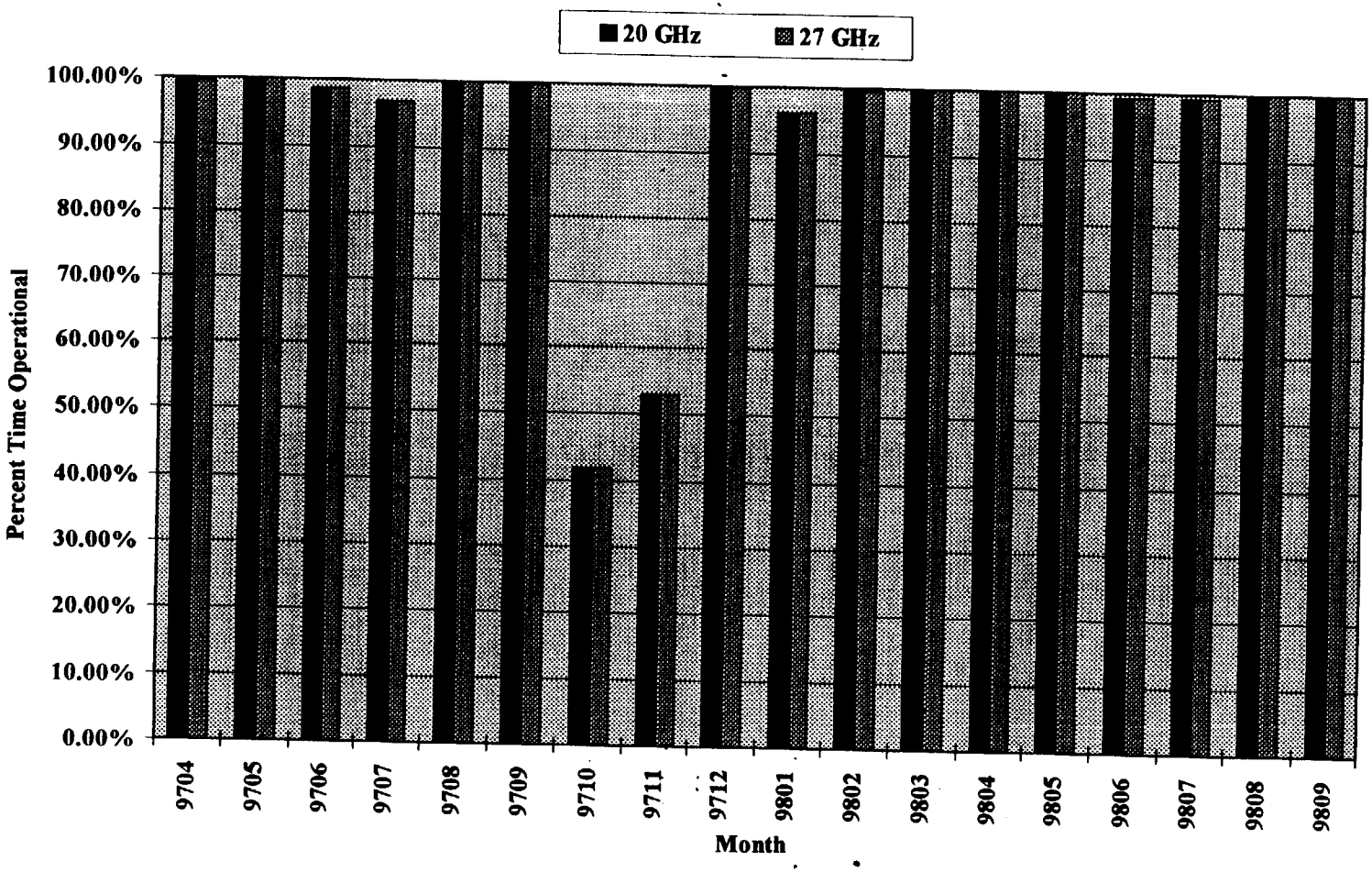
October 22, 1998

OUTLINE

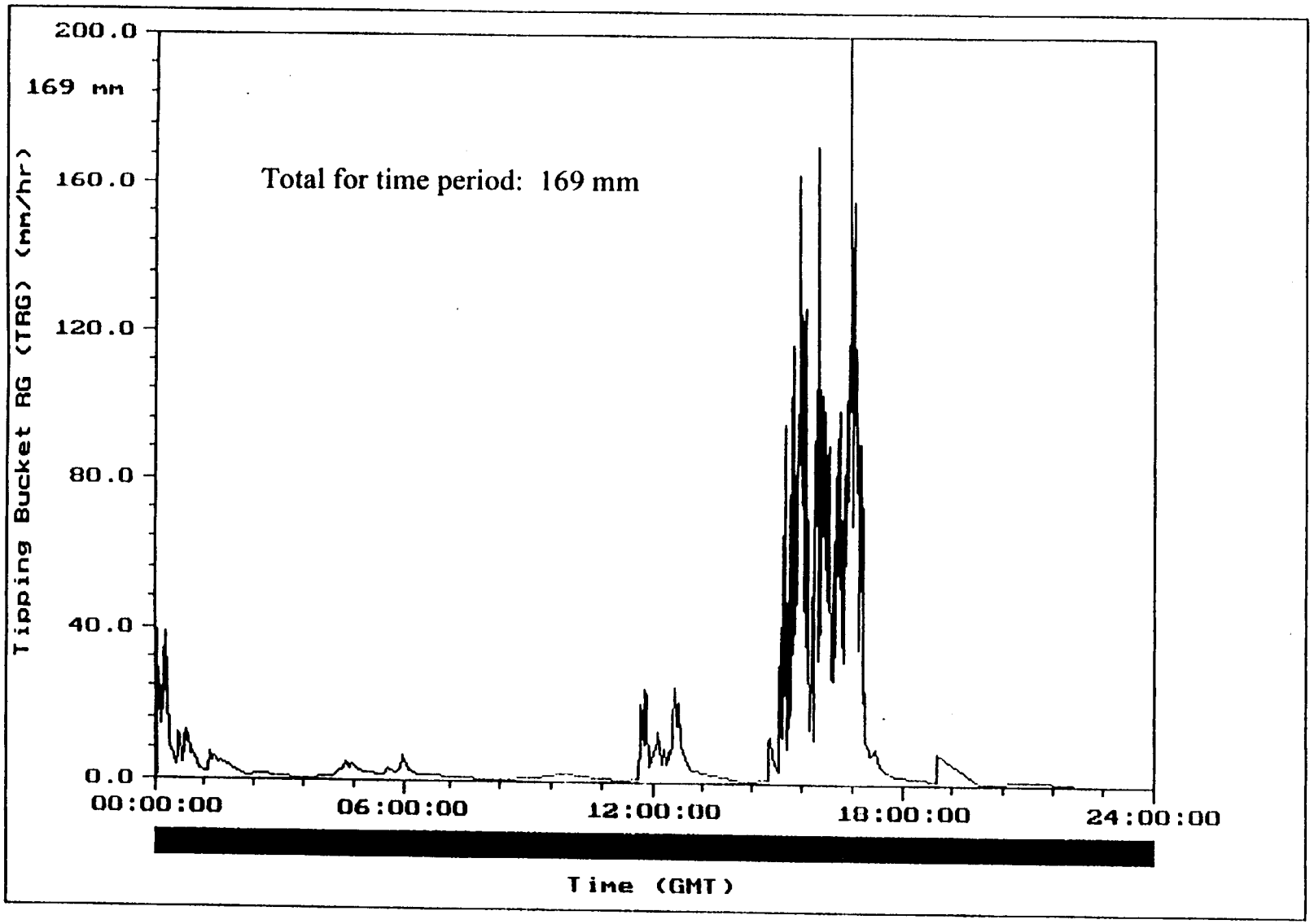
- Florida Program Overview
- Site Operations
- AGA Model Comparisons
- Diversity Program
- Conclusions

FLORIDA PROGRAM GOALS

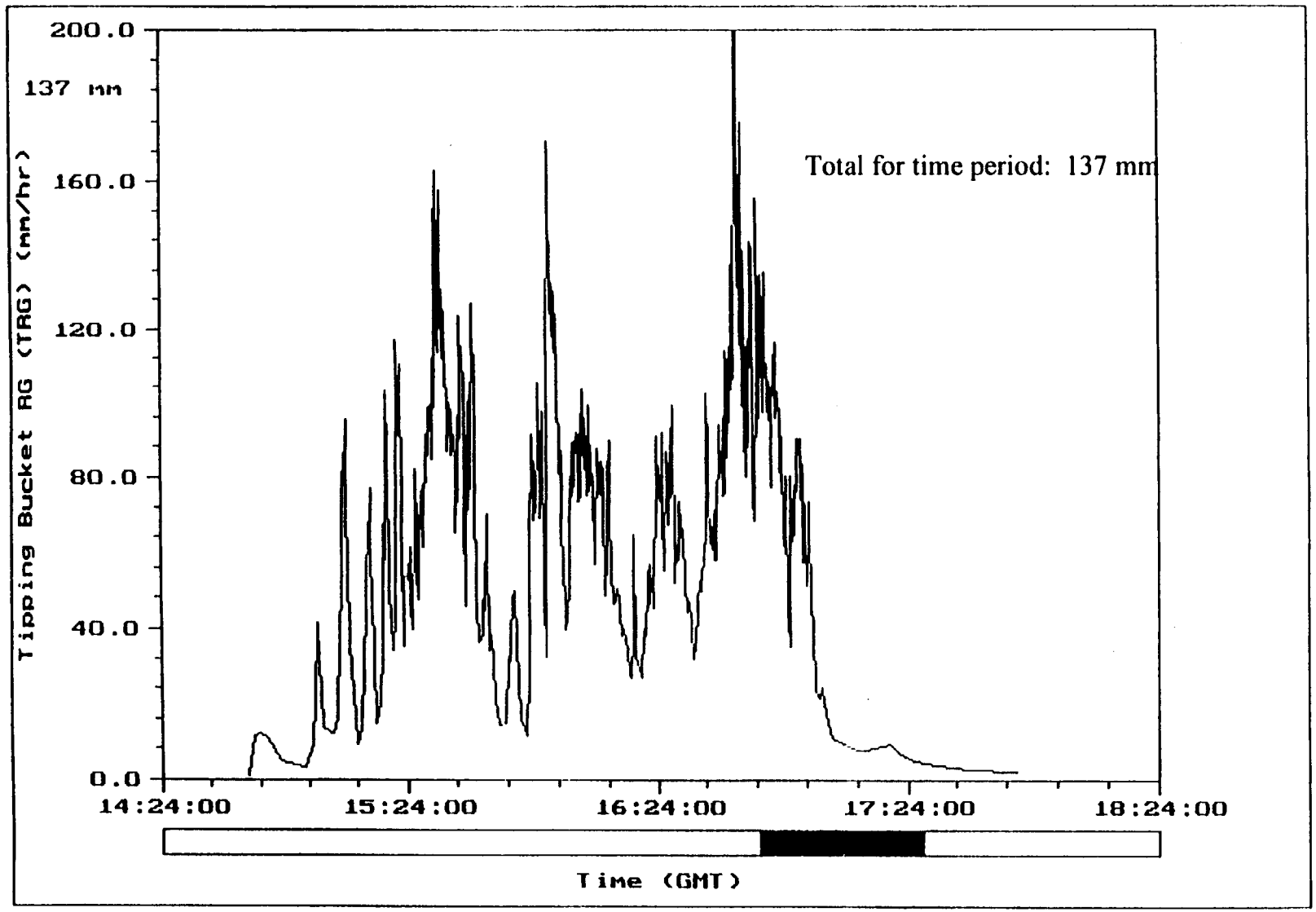
- Generate CDF's For Sub-tropical Regions
- Sub-tropical Fade Duration Statistics
- Seasonal and Diurnal Statistics
- Diversity Gain
- Sub-tropical Propagation Models



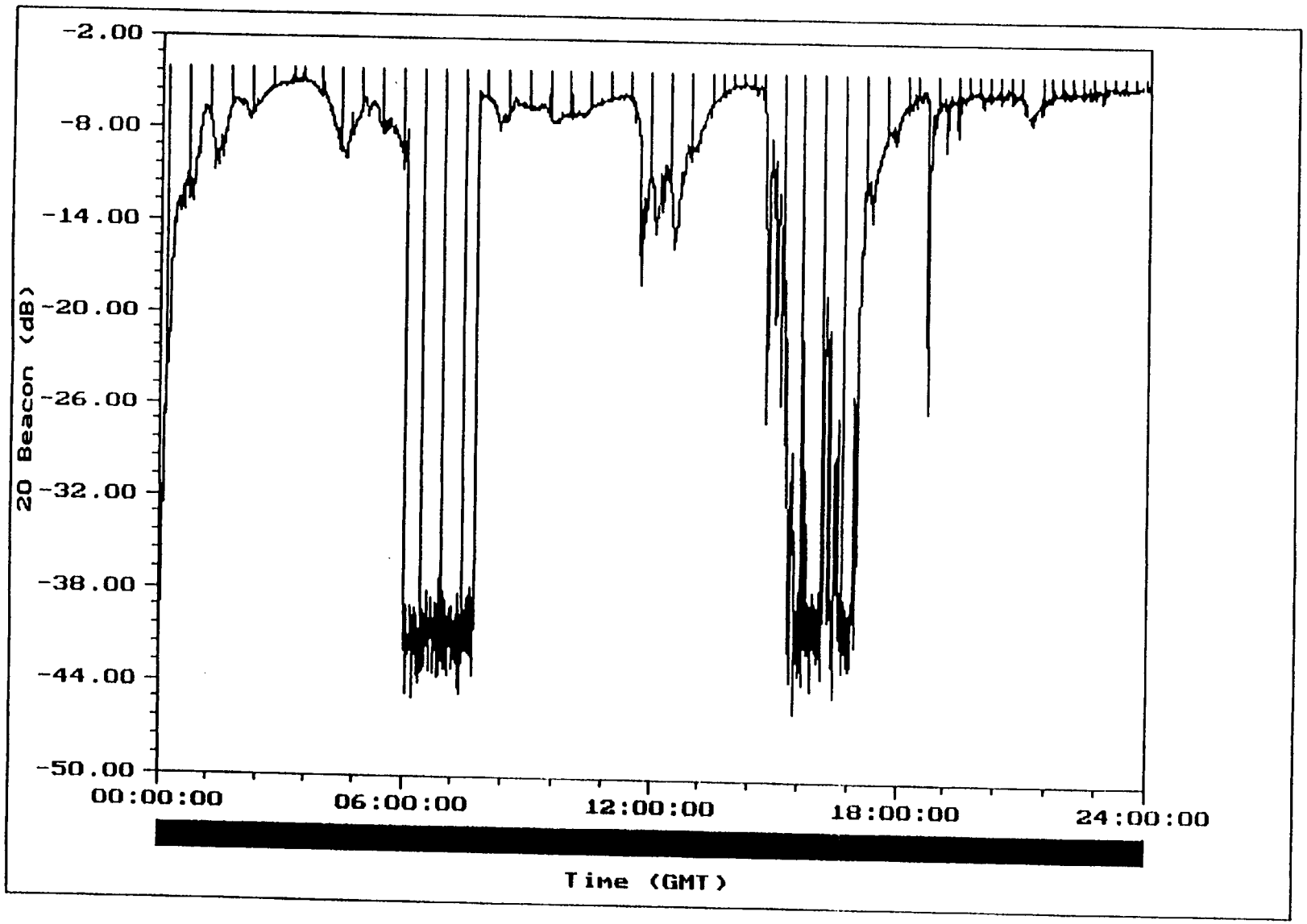
Operational Status of Receiver/Radiometer (04/97-09/98)



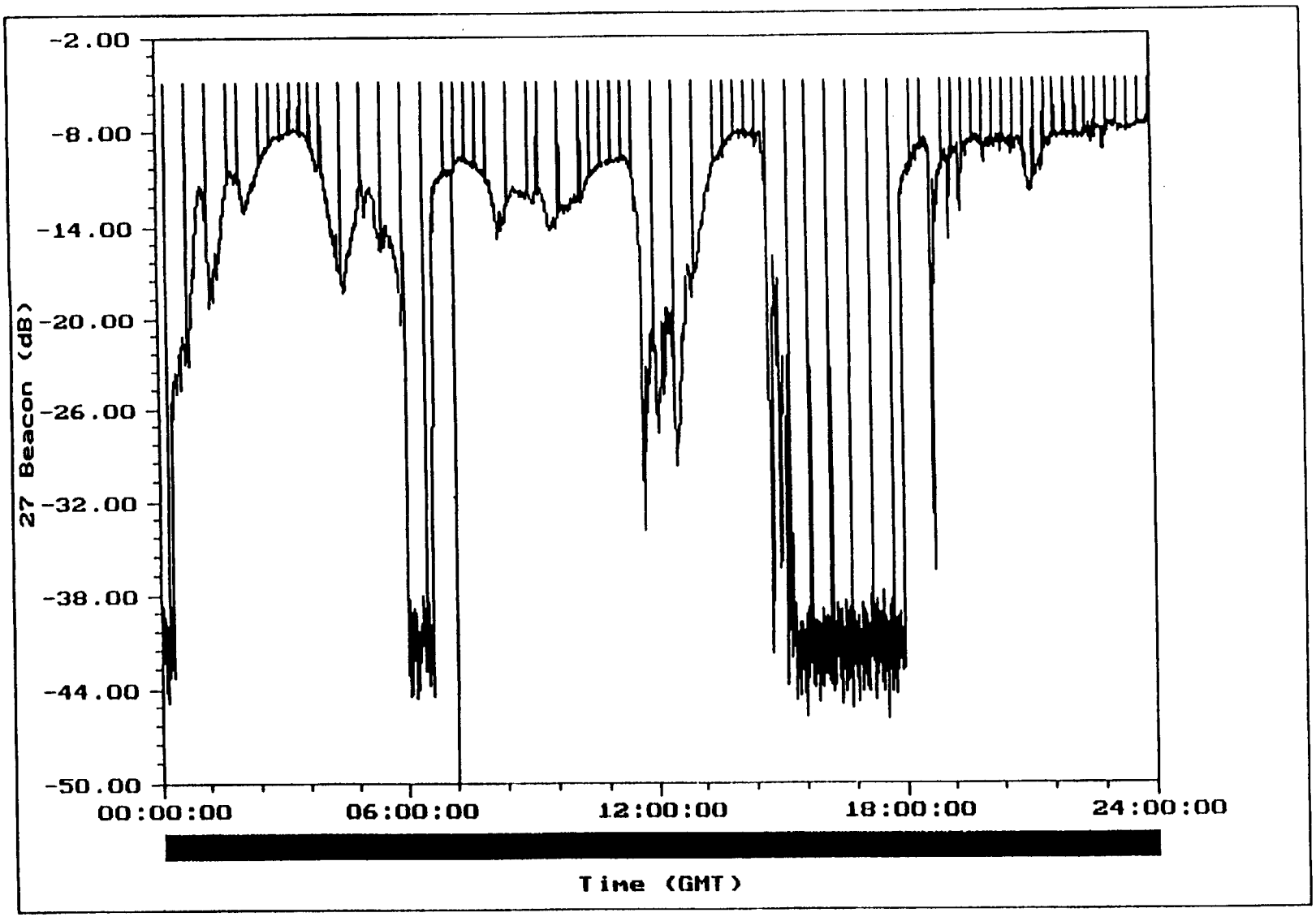
Intense Rain Event (09/20/98)



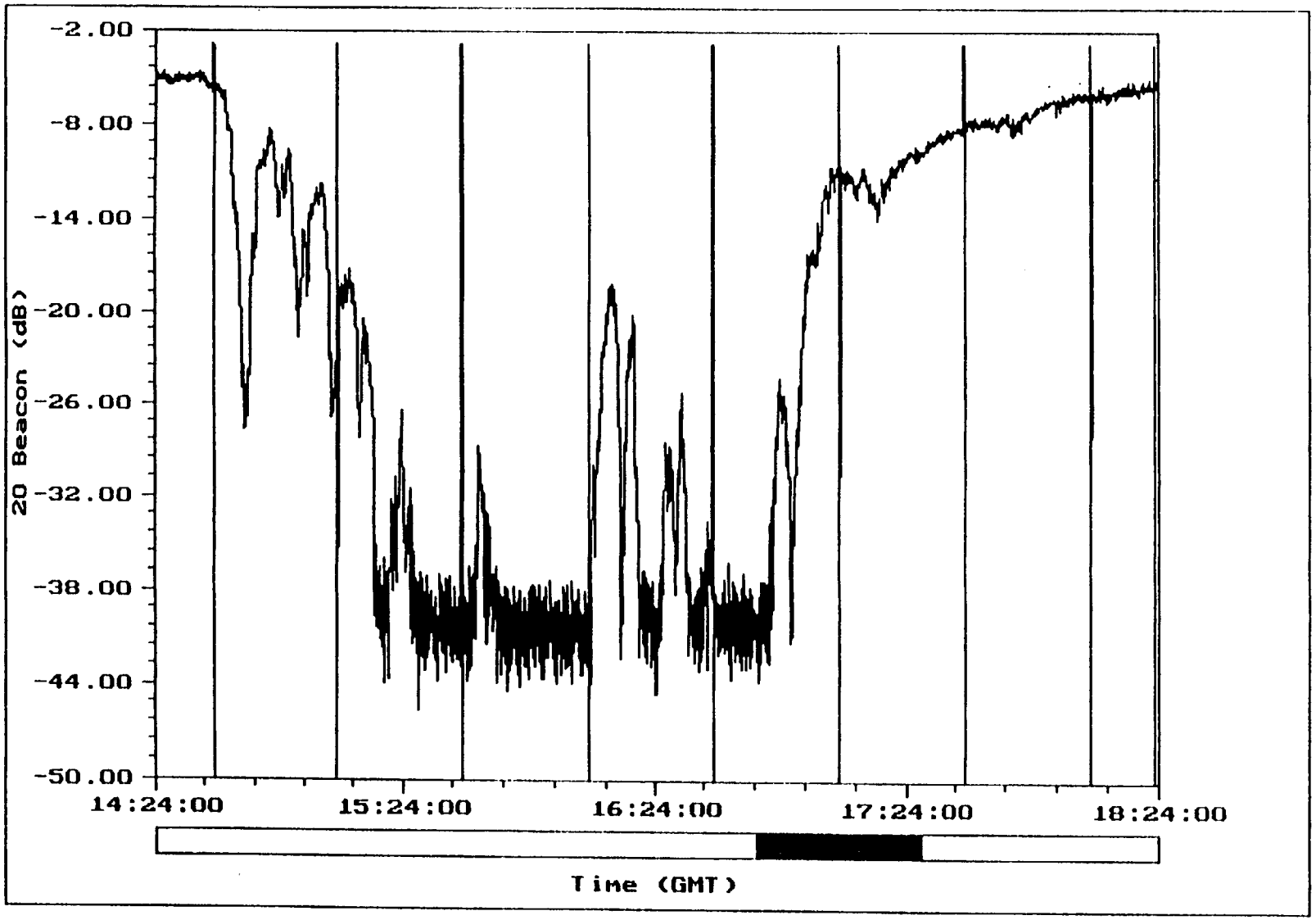
Intense Rain Event (09/20/98)



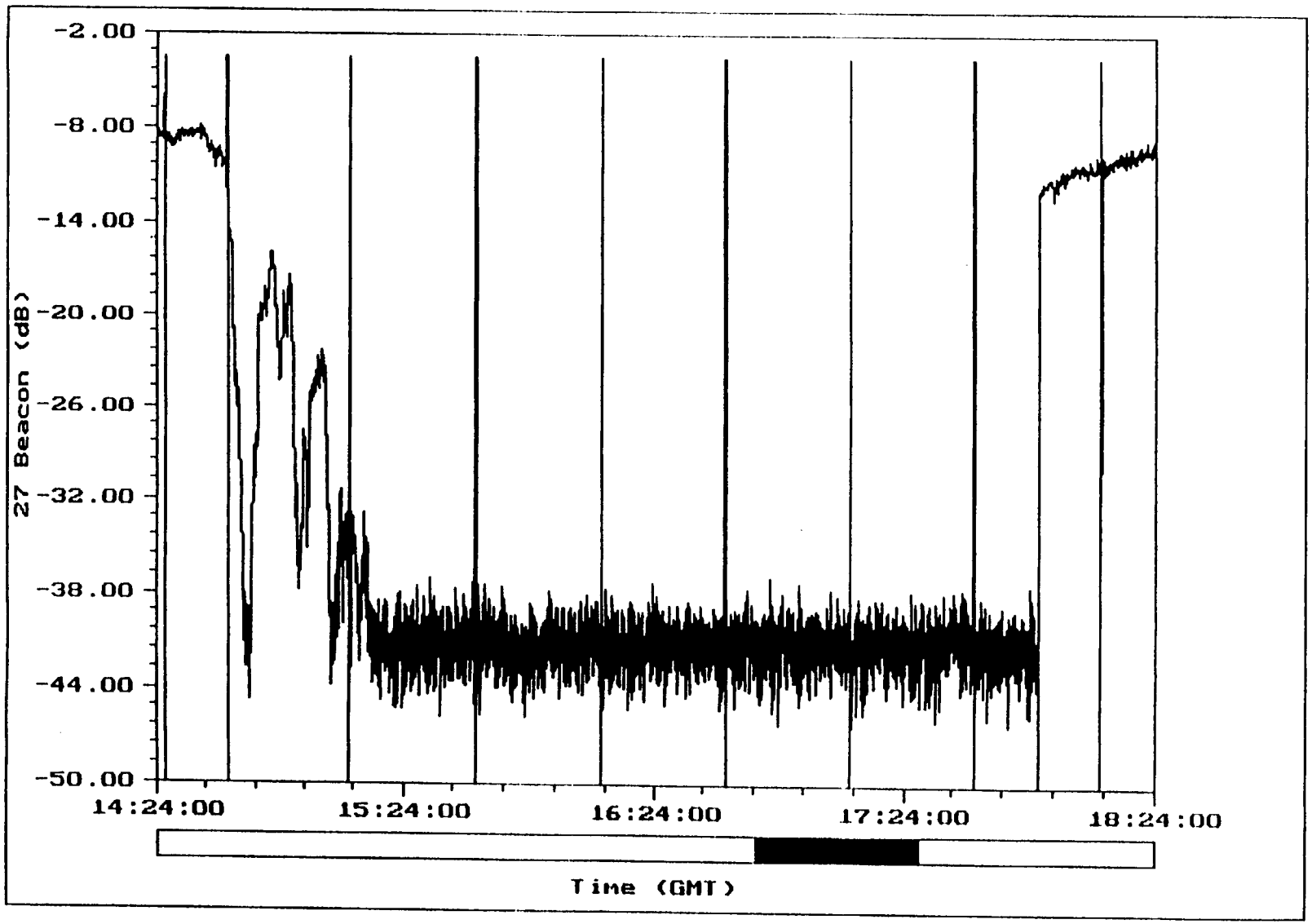
Intense Rain Event (09/20/98)



Intense Rain Event (09/20/98)

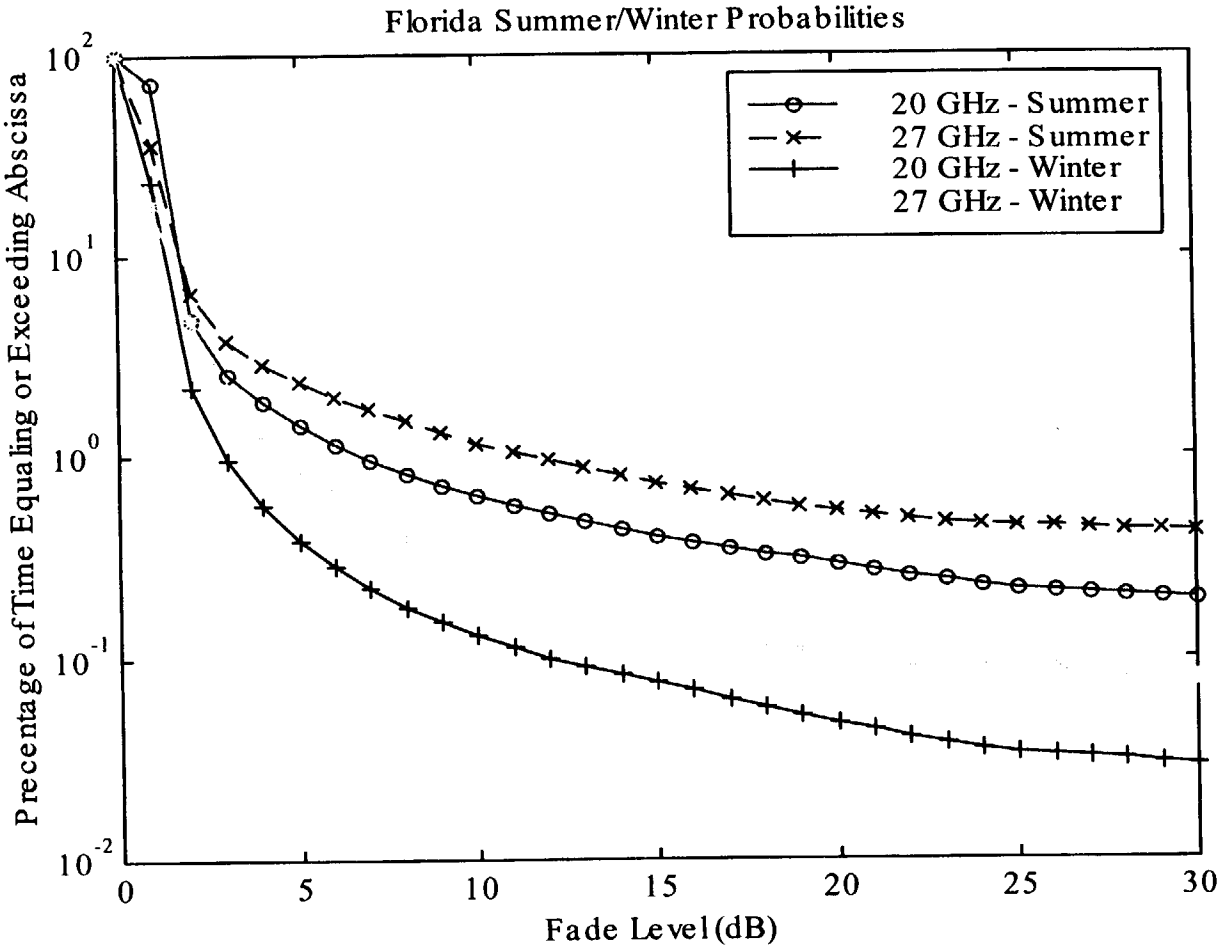


Intense Rain Event (09/20/98)

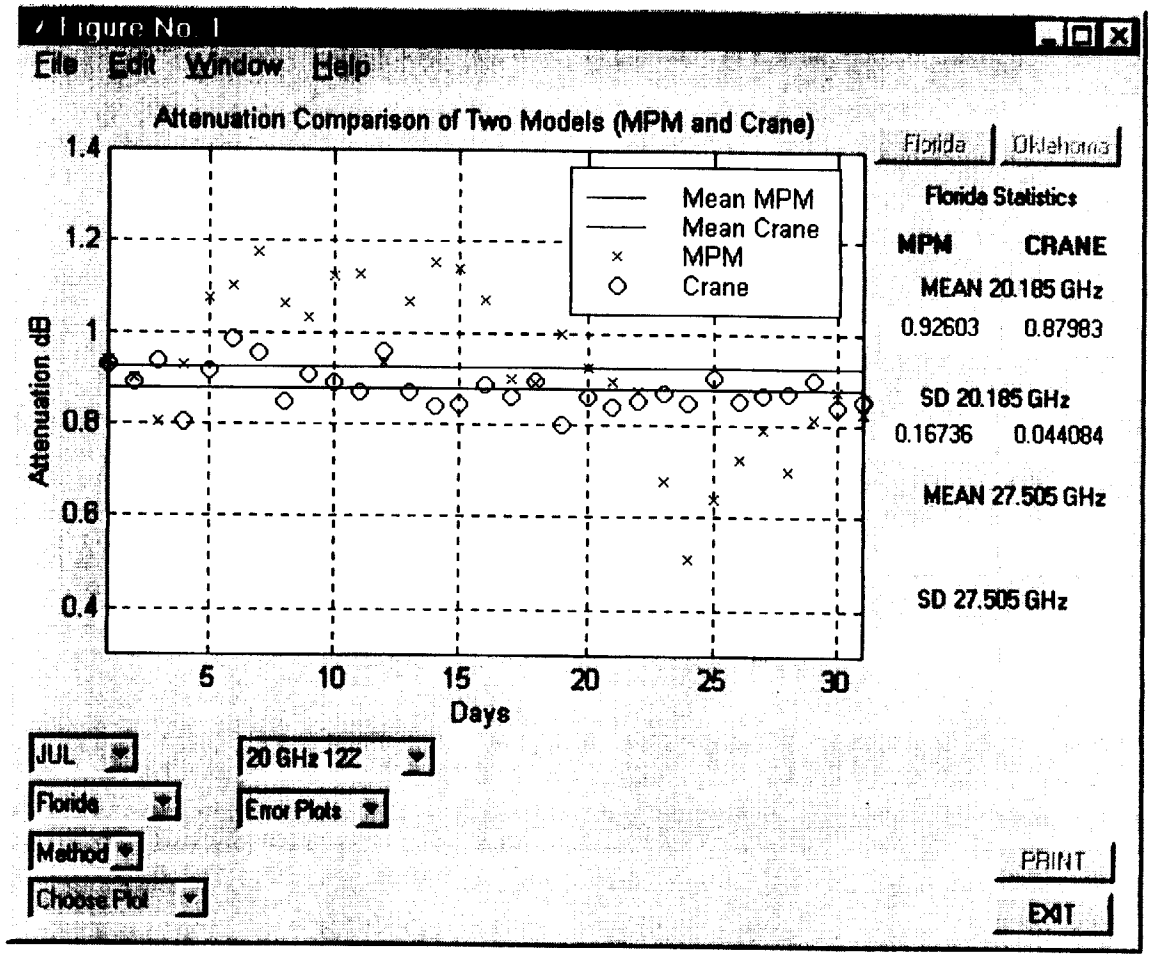


Intense Rain Event (09/20/98)

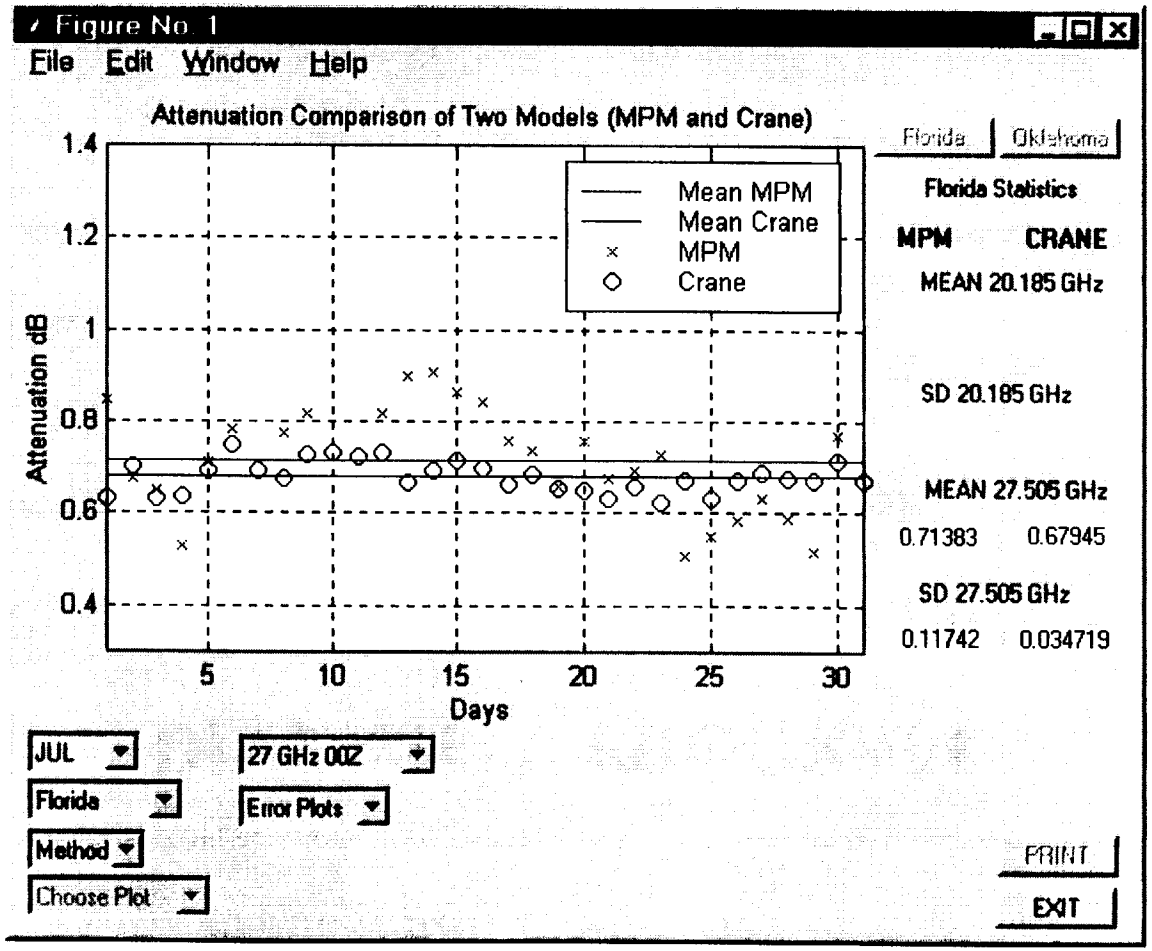
FLORIDA SUMER/WINTER PROBABILITIES



20 GHz Model Comparison - 12Z



27 GHz Model Comparison - 00Z



DIVERSITY PROGRAM

- Diversity Improvement in Tropical Regions
  - 20 GHz Transportable Terminal
    - 1.2 m Prodelin Antenna
    - APT Digital Receiver
- Short Baseline Improvement
  - < 5km Separations
- Spatial Diversity Improvement
  - GBS Satellite 20.7 GHz Beacon at 17W

INCLINED ORBIT OPERATIONS

- Tracking Mount Requirements
  - VSAT Antenna Experience
- Replacement/Refurbished Antenna
  - Mitigate Wet Antenna Effects
  - Validate Florida APT Data Base
- Faculty and Student Support

CONCLUSIONS

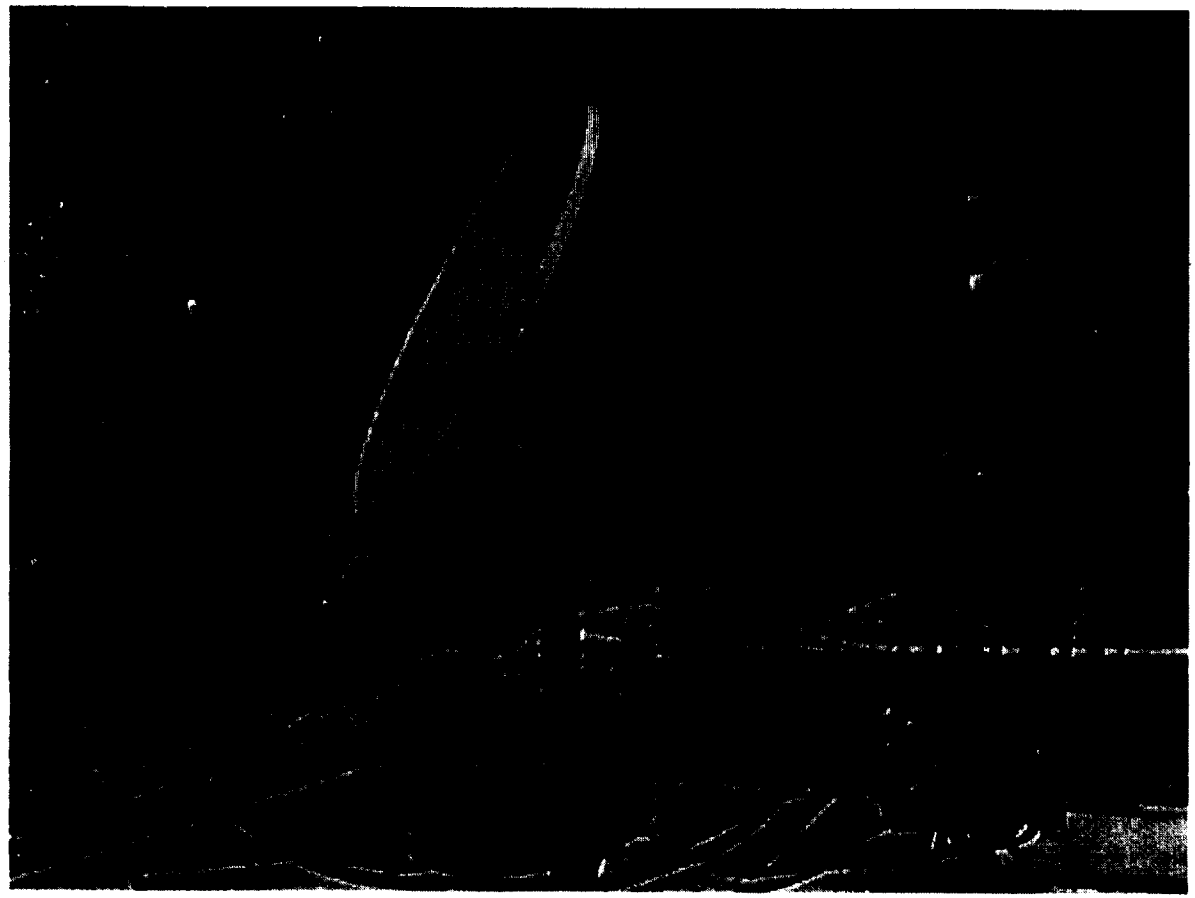
- Normal APT Terminal Operations
- Validation of Crane Model for Florida
- Rain Shower Dependence of Diversity Gain
- Recommend Inclined Orbit Operations

New Mexico ACTS Propagation Terminal Status

Stephen Horan, Atle Borsholm and
Xueyuan Tang
New Mexico State University

October 1998

NM APT



Topics

- Changes
- Availability
- Analysis

Changes

- Thermal cutout switch failed in the receiver enclosure at the end of May; replaced it during July
- WWW just stopped receiving; still diagnosing the problem

Availability

- Lost data in June due to thermal switch failure
- Lost some data in October - cause unknown but probably due to someone laying an object on the keyboard
- No rain events lost

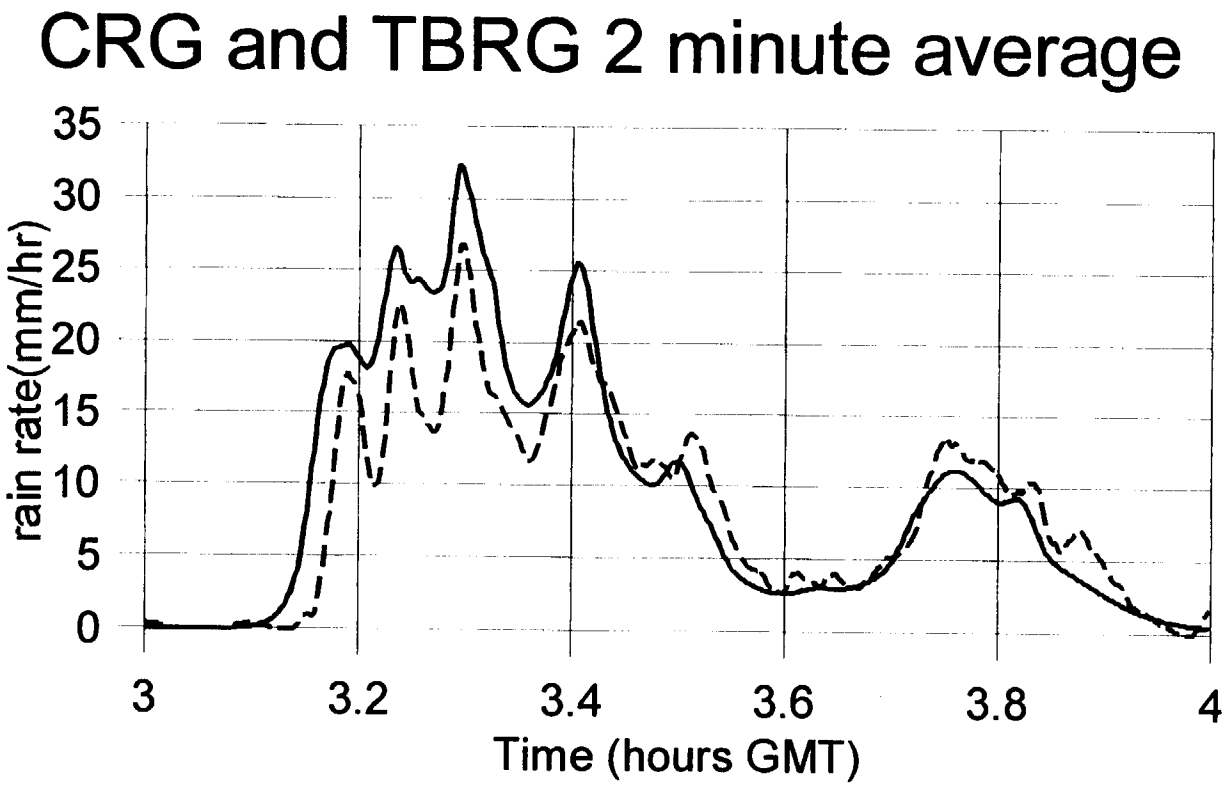
Availability

Month	Data Seconds	Gap Seconds	Availability
June	1999492	592508	77.1%
July	2675824	2576	99.9%
August	2768400	0	100.0%
September	2591758	242	100.0%
Total	10035474	595326	94.4%

Analysis

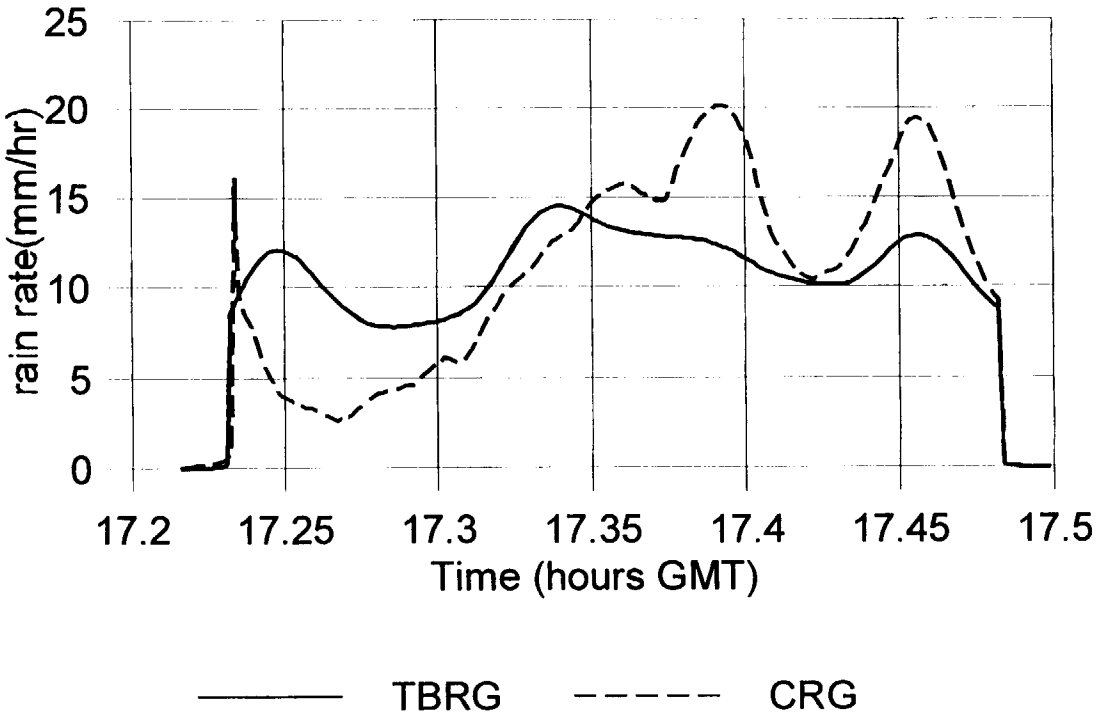
- Detailed examination of the rain rates derived from the Capacitive Rain Gauge and the Tipping Bucket Rain Gauge
  - Total accumulations show the same general values (usually to within ± 1 mm on all but trace events)
  - Instantaneous rain rates can be very different with the TBRG looking more realistic

Analysis


CRG and TBRG 2 minute average
rain rate(mm/hr)
35
30
25
20
15
10
5
0
3
3.2
3.4
3.6
3.8
4
Time (hours GMT)
TBRG
CRG

Analysis

CRG and TBRG 2 minute average (Continued)



Project: Overall Statistical Modeling of Space-to-Ground Links

1. Define for each user population
   a. Longitude and latitude
   b. ITU and Crane rain region
   c. Population density database

2. Define for each satellite system
   a. Orbital dynamics
   b. Number of satellites in the constellation
   c. Satellite constraints e.g., minimum elevation angle

3. Define propagation time-varying effects
   a. For each user location, each satellite system will have a Probability Density Function (PDF) that describes the percent of time the satellite has a given elevation angle
   b. Use the elevation PDF to generate the PDF for propagation effects
   c. Estimate overall propagation effects weighted by
      i. Satellite elevation PDF
      ii. Rain, scintillation, gas, etc. by frequency
      iii. Number of satellites available to a user
   d. Weight results by population density to optimize service needs

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Stanford Telecom / New Mexico State University

ACTS Propagation Measurements Program

Data Analysis Summary

Cynthia Grinder
Jennifer Pinder
Louis J. Ippolito
Stephen Horan
Atle Borsholm

APSW XXIII
October 22-23, 1998
Norman, OK

ACS Stanford Telecom

Agenda

- **Introduction**
  - ➢ Experiment objectives and configuration
- **NM ACTS K_A band measurements and analysis**
  - ➢ Four years (12/93-11/97) of propagation statistics
  - ➢ Annual model comparisons
  - ➢ Seasonal statistics
  - ➢ Almost five years (12/93-8/98) of propagation statistics
- **Summary and future activities**

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STel ACTS Propagation Experiment Objectives

- **Measure and evaluate K_A band propagation effects and link performance for New Mexico**
- **Develop long-term statistics and prediction modeling techniques for the New Mexico climate region to be used for advanced satellite system planning and design**

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New Mexico APT

- **Measured parameters**
  - ➢ Beacons: 20.185 GHz and 27.505 GHz
  - ➢ Radiometers: 20 GHz and 27.505 GHz
  - ➢ Rain rate (CRG, TBG)
  - ➢ Temperature, Relative Humidity, Wind Vector, Barometric Pressure
- **Rain Region:**
  - ➢ Crane Region: F
  - ➢ ITU Region: E
- **Site Specific Geometrical Parameters:**
  - ➢ Elevation Angle: 51°
  - ➢ Polarization Tilt: 79°
  - ➢ Altitude: 1.459 km
  - ➢ Latitude: 32° 32' 40" N & Longitude: 106° 36' 48" W

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Definition of Attenuation Terms

- **AFS: Attenuation wrt Free Space**

  Difference between the received beacon level and the received level if in a vacuum. AFS includes attenuation due to atmospheric absorption, rain, clouds, and scintillation.

- **ARD: Radiometrical Derived Attenuation**

  Attenuation measurements from radiometers. Comparable to AFS.

- **ACA: Attenuation wrt Clear Air**

  The difference between the received beacon level and the expected level due to atmospheric absorption (AGA). ACA includes rain, clouds, and scintillation. ACA=AFS-AGA.

- **ARS: Statistical Attenuation Ratio**

  Ratio of equiprobable attenuation levels at two frequencies of interest.

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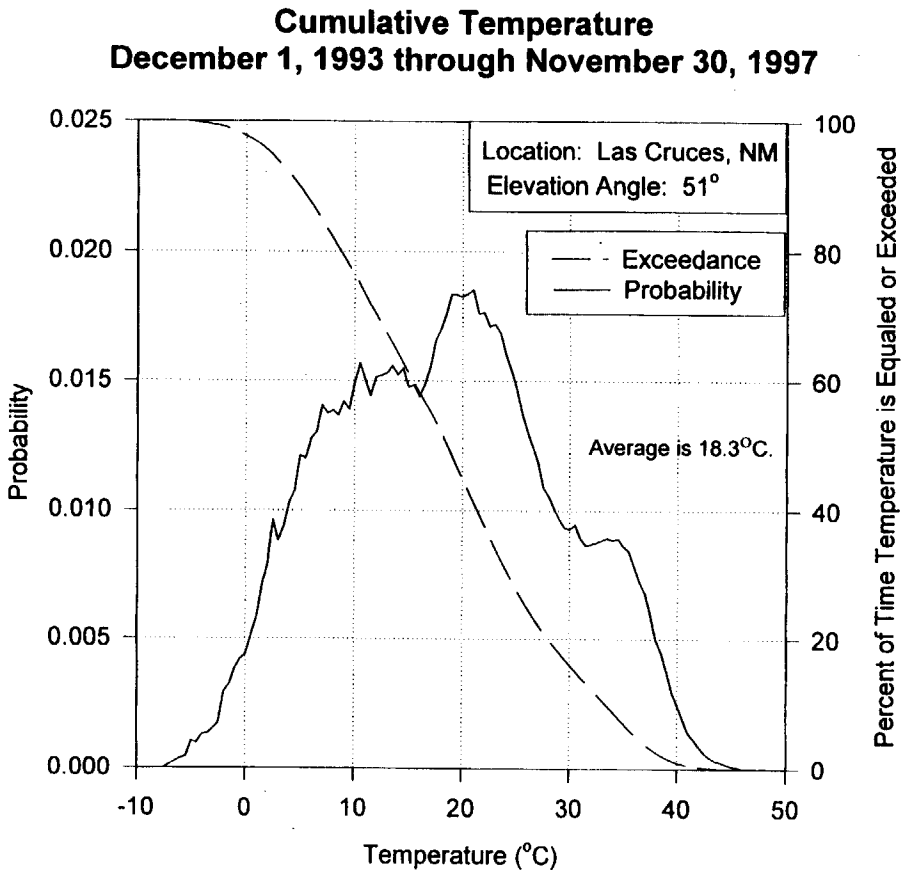
Cumulative Surface Temperature



- Historical weather data shows the average annual temperature for the New Mexico site to be 17°C.

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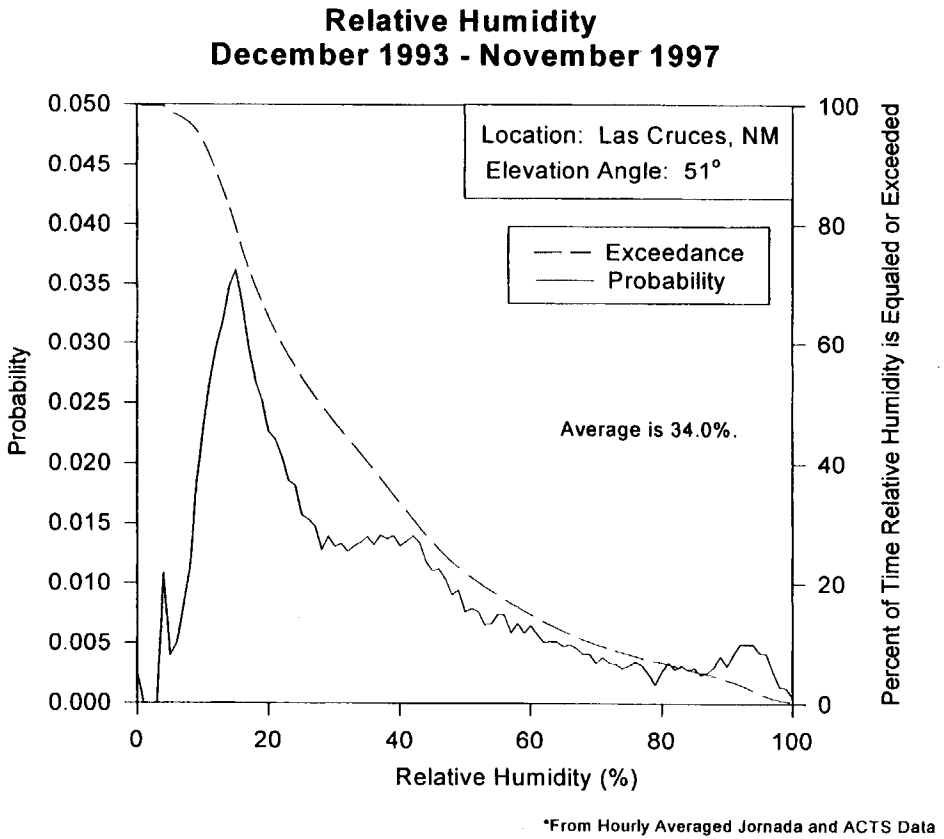
Cumulative Relative Humidity



- Historical weather data shows the average annual relative humidity for the New Mexico site to be 47%.

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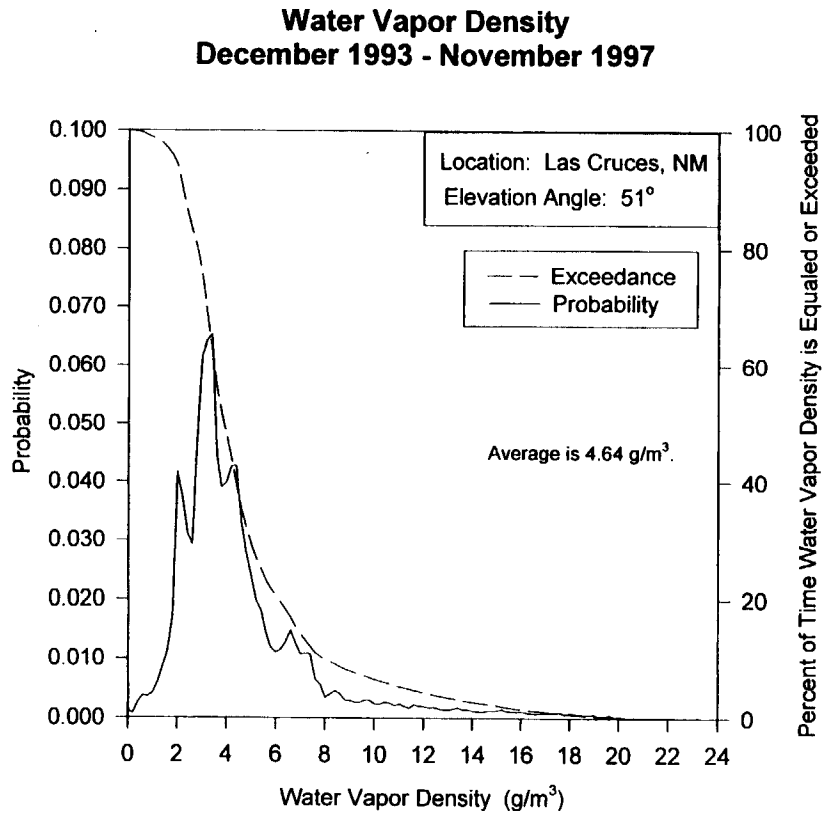
Cumulative Water Vapor Density



*Calculated from hourly temperature averages and Jornada Relative Humidity data

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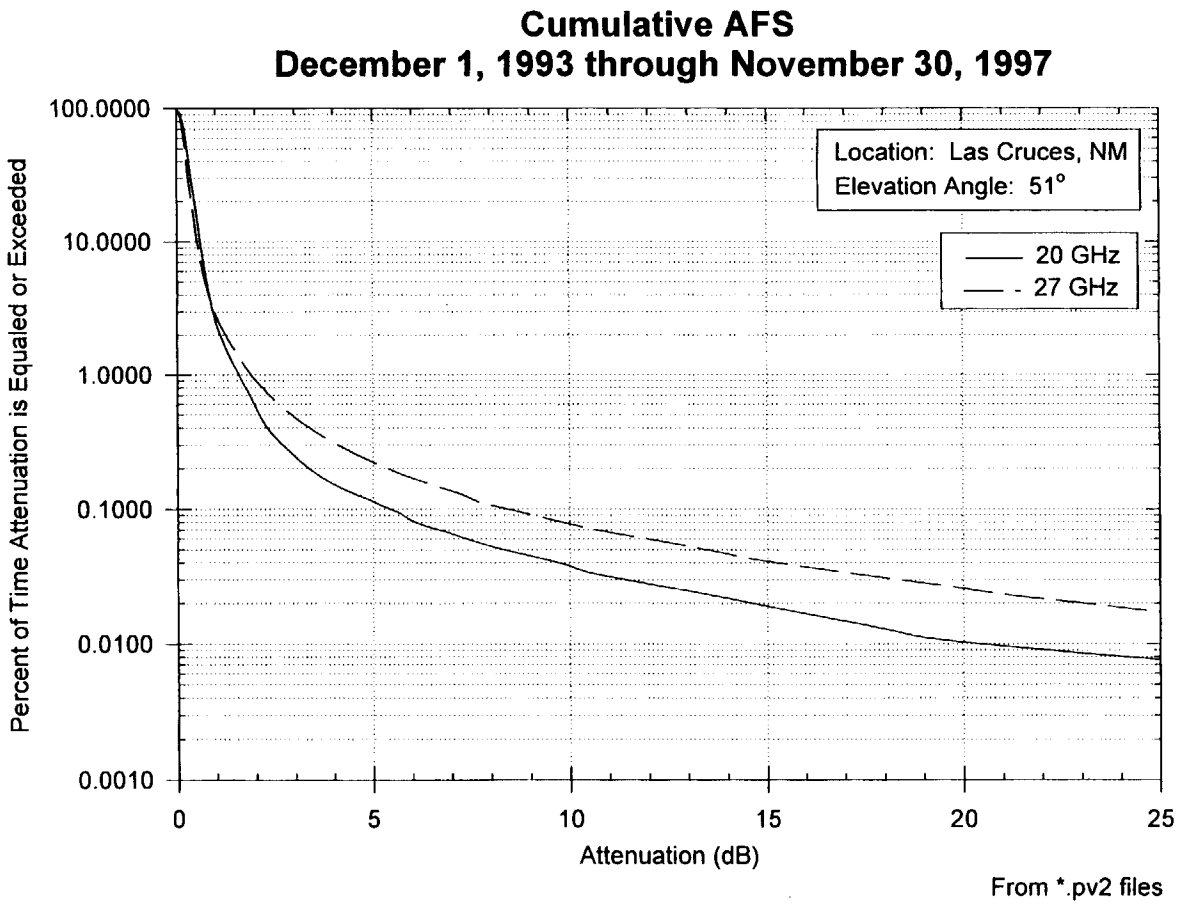
Attenuation wrt Free Space (AFS)



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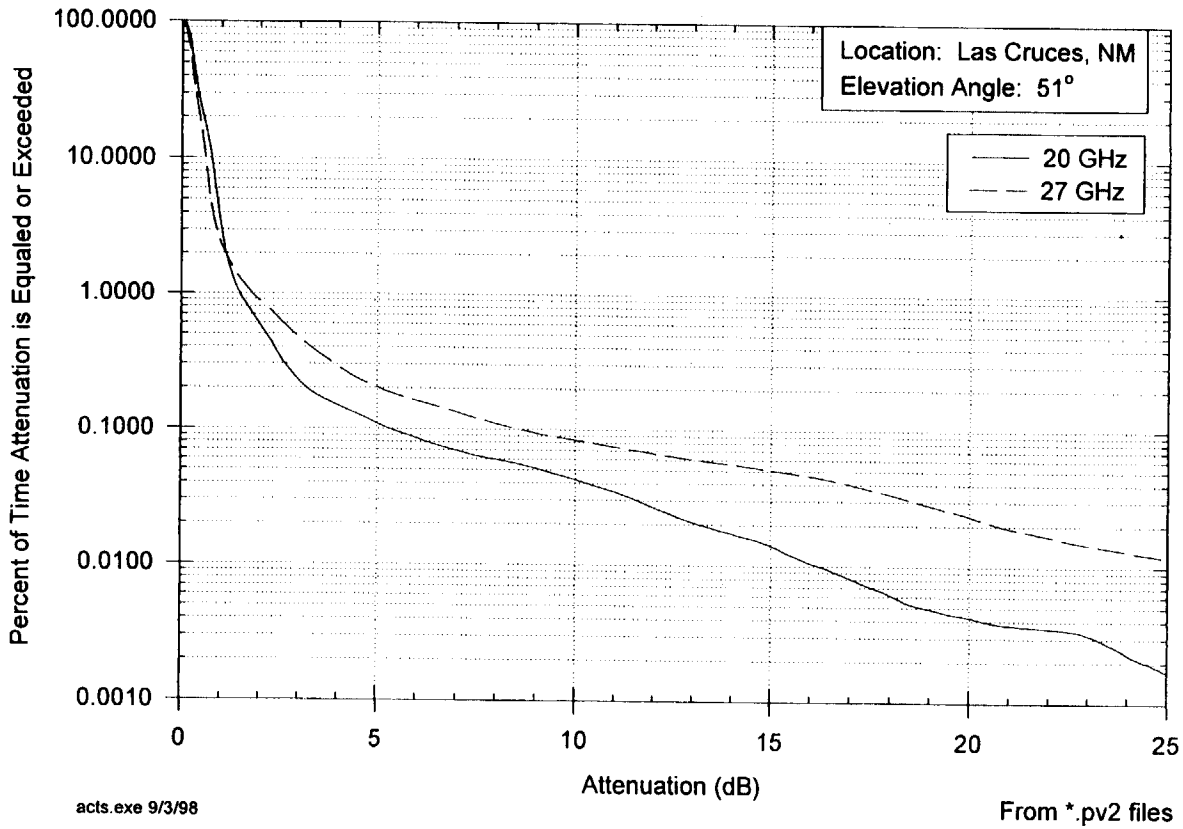
Attenuation wrt Free Space (AFS)

Cumulative AFS 1998
(December 1997 - August 1998)



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New Mexico ACTS Statistics Summary (Cont.)

- **Measured Link Performance for 12/93-8/98 (*.pv2)**

		20.2 GHz		27.5 GHz	
	% Availability	99.9	99.99	99.9	99.99
	% Outage Time	0.1	0.01	0.1	0.01
Attenuation	1994	5.4 dB	17.2 dB	8.5 dB	>25.0 dB
	1995	3.7 dB	19.4 dB	6.0 dB	>25.0 dB
	1996	6.3 dB	>25.0 dB	10.0 dB	>25.0 dB
	1997	5.3 dB	18.2 dB	9.3 dB	>25.0 dB
	4 Year	**5.4 dB**	**20.0 dB**	**8.4 dB**	**>25.0 dB**
	1998	5.2 dB	16.0 dB	8.6 dB	>25.0 dB

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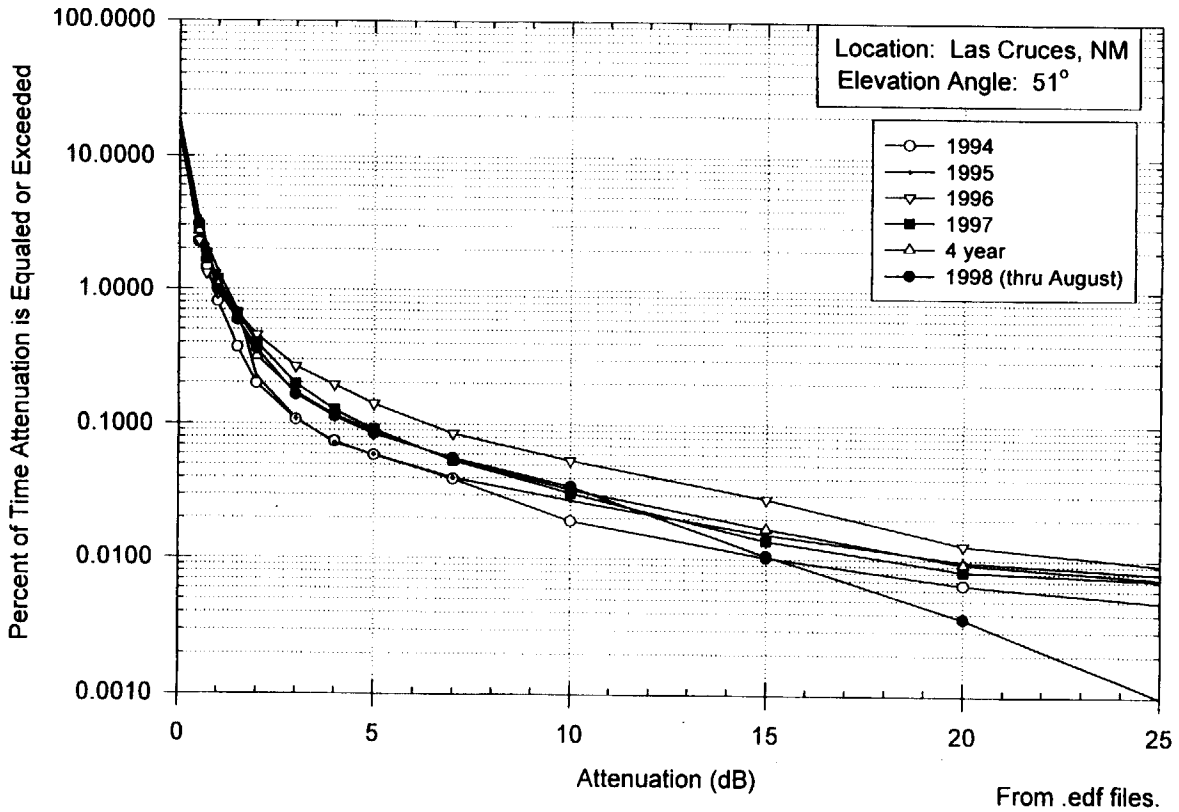
Annual ACA Empirical Distributions (20 GHz)

ACA for December 1993- August 1998
(20GHz)



From .edf files.

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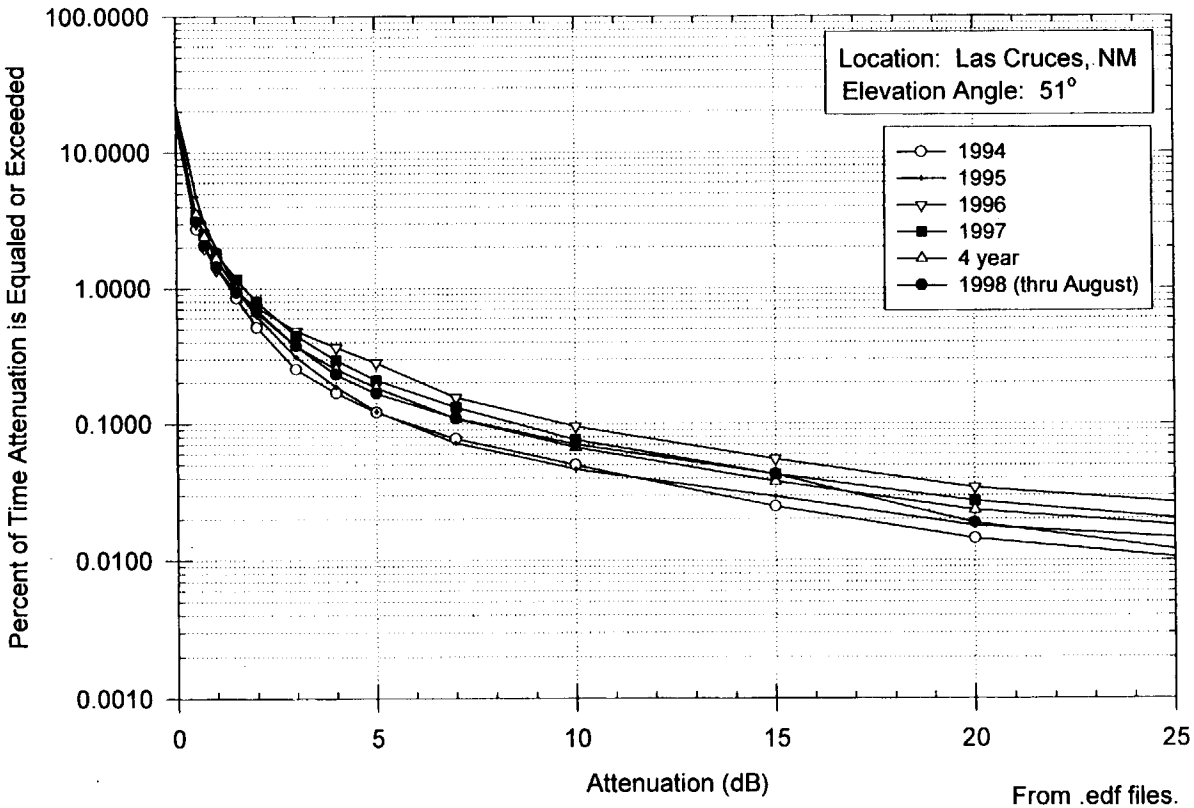
Annual ACA Empirical Distributions (27 GHz)

ACA for December 1993- August 1998
(27 GHz)



From .edf files.

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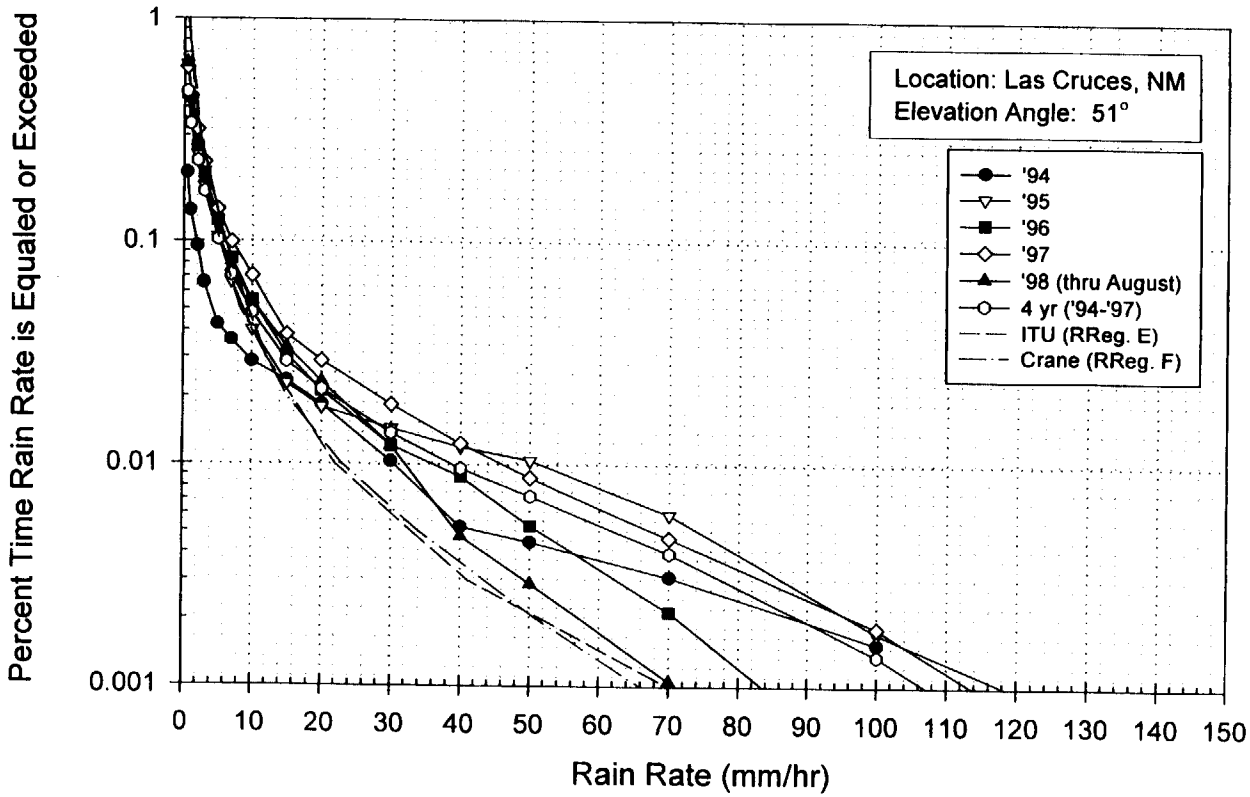
Annual Rain Rate Empirical Distributions from the Tipping Bucket

Annual Rain Rates for December 1993 - August 1998



From *edf files using tipping bucket.

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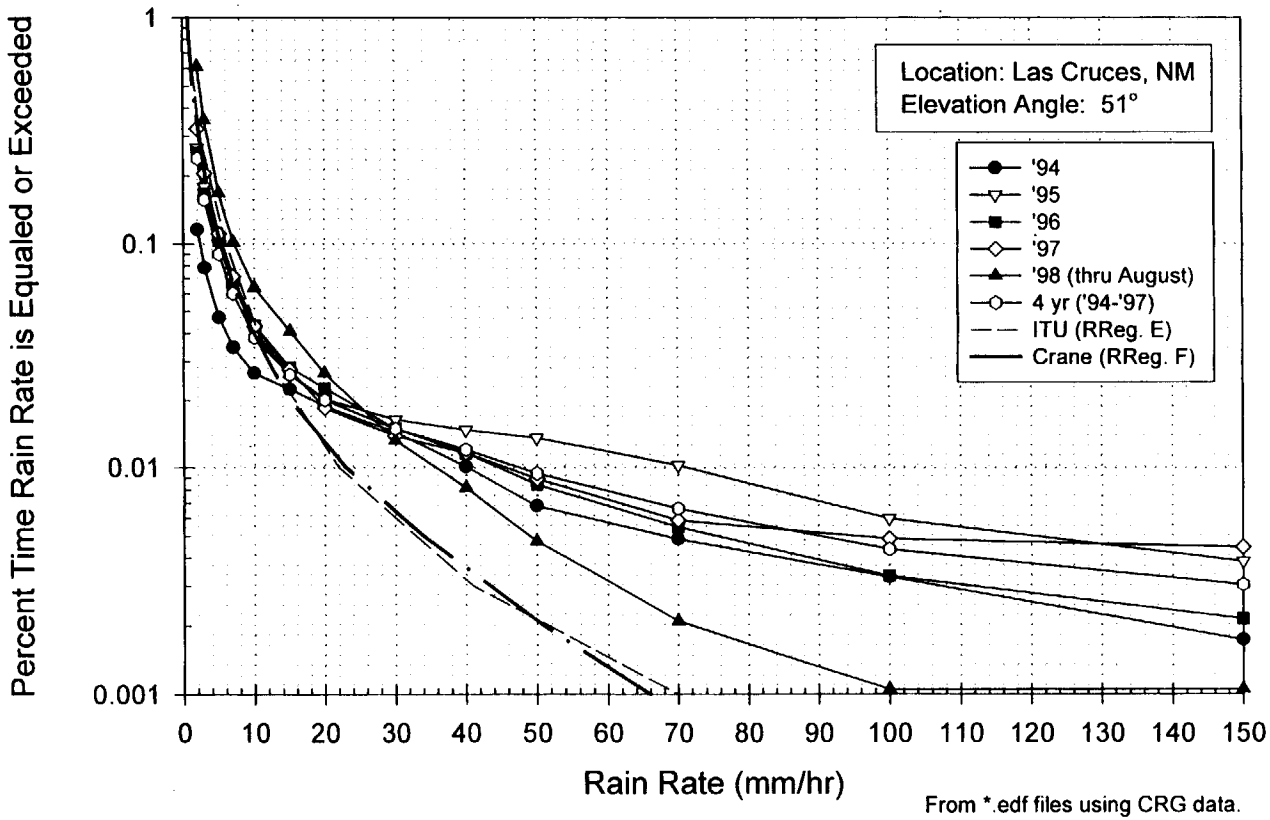
Annual Rain Rate Empirical Distributions from CRG

Annual Rain Rates for
December 1993 - August 1998



From *.edf files using CRG data.

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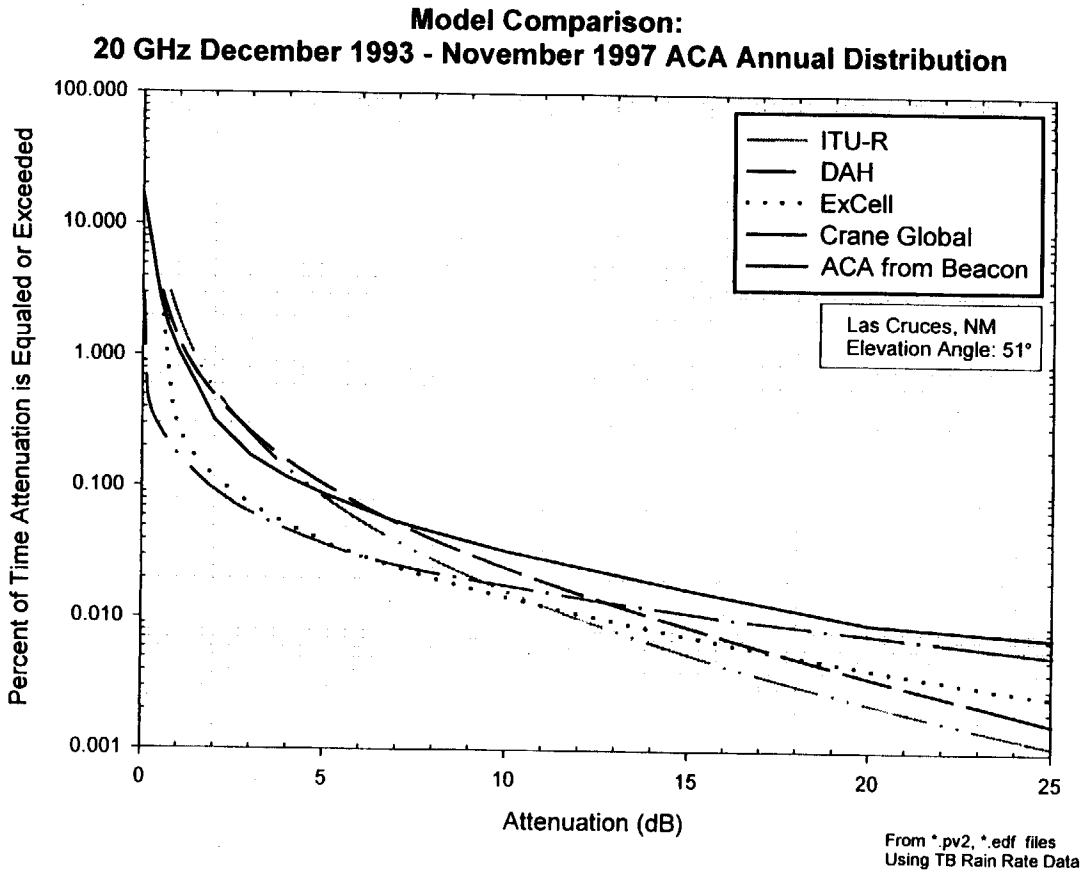
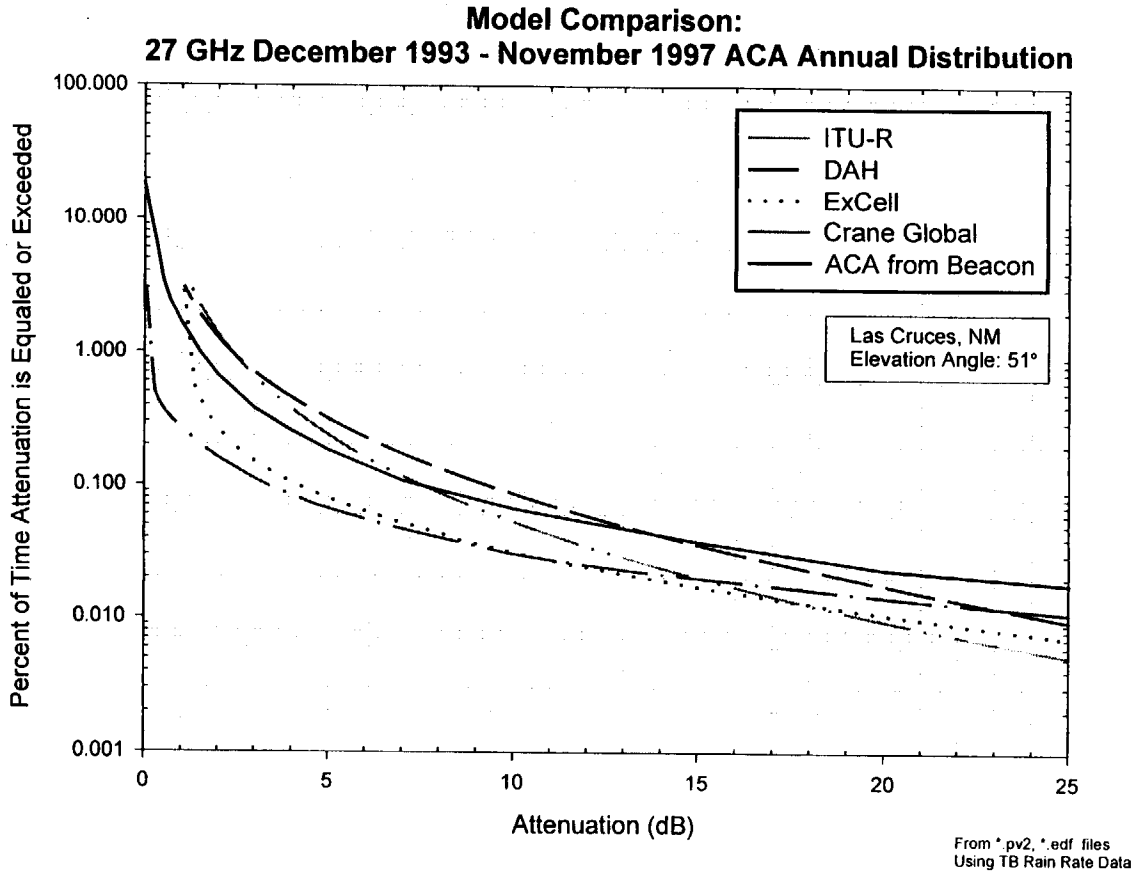
Model Comparison: ACA 4yr Distribution (20 GHz)



- Rain rates used come from tipping bucket data.

Model Comparison: ACA 4yr Distribution (27 GHz)



- Rain rates used come from tipping bucket data.

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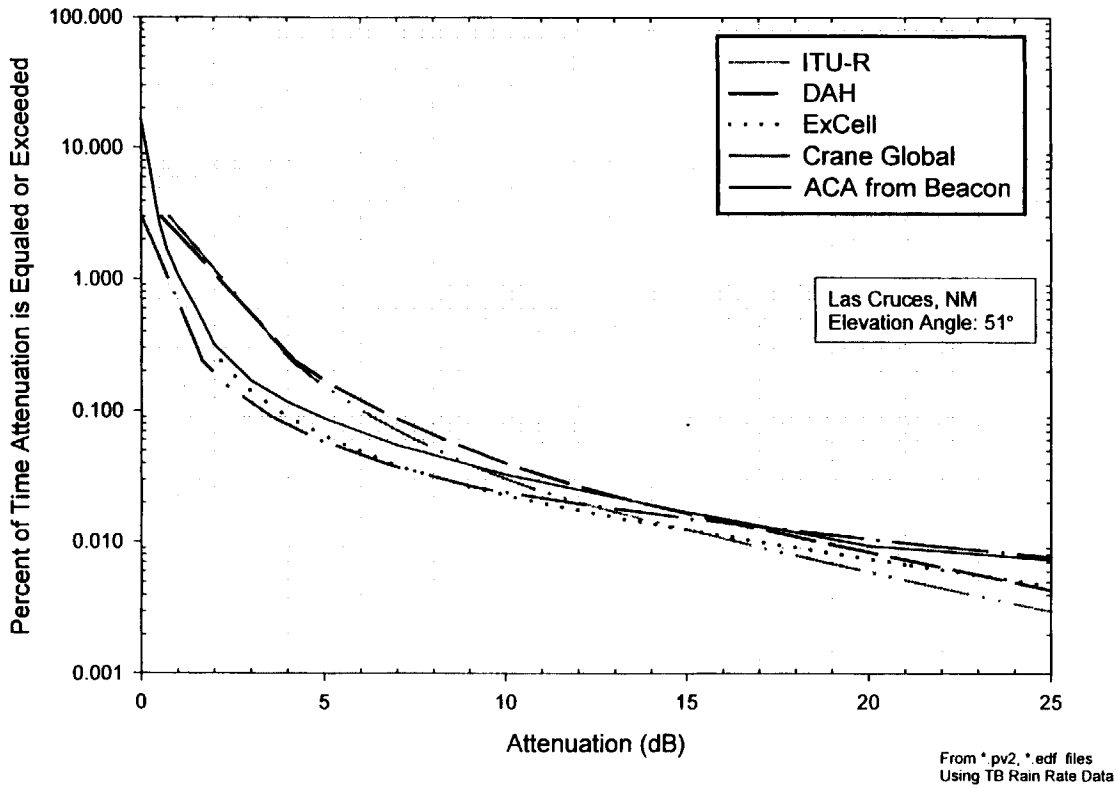
Model Comparison + Wet Surface Effects (20 GHz)

Comparison of Rain Attenuation Models + Wet Surface Effects to 20.2 GHz NM Data: December 1993 - November 1997 ACA Annual Distribution



✣ Rain rates used come from tipping bucket data.

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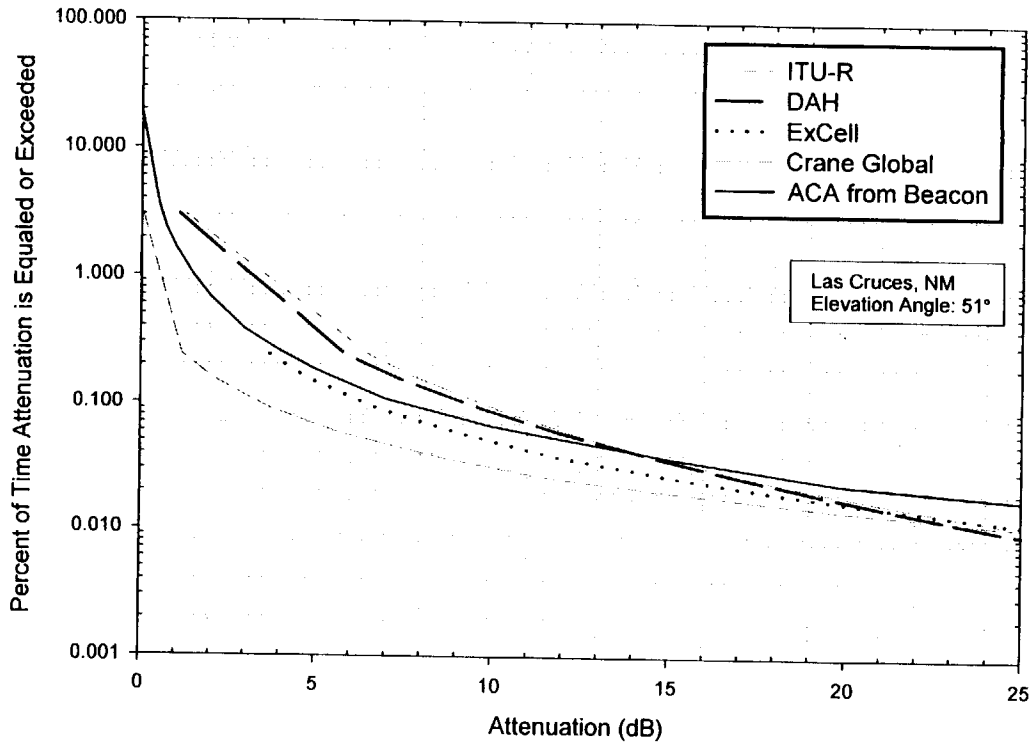
Model Comparison + Wet Surface Effects (27 GHz)

Comparison of Rain Attenuation Models + Wet Surface Effects to 27.5 GHz NM Data: December 1993 - November 1997 ACA Annual Distribution



From *.pv2, *.edf files
Using TB Rain Rate Data

✣ Rain rates used come from tipping bucket data.

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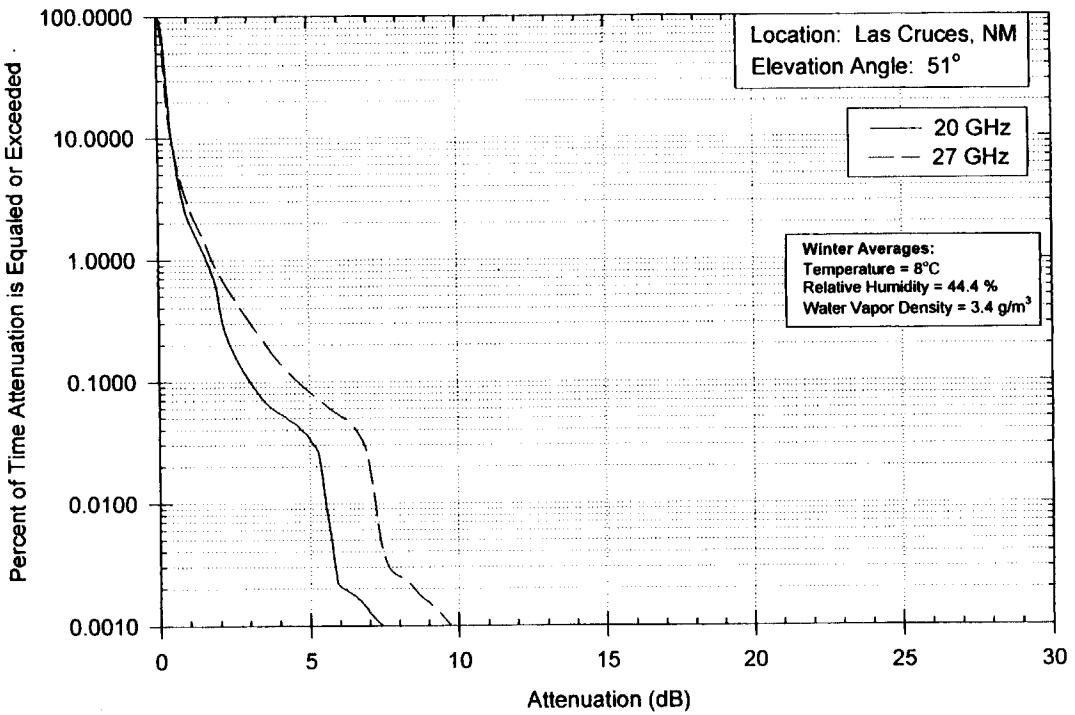
Five Year Winter AFS Statistics

AFS for Winter (December, January, February) 1993-1997



From *.pv2 files

- Historical weather data for the New Mexico site: For Winter, the average temperature is 7.7°C and the average relative humidity is 40.6%.

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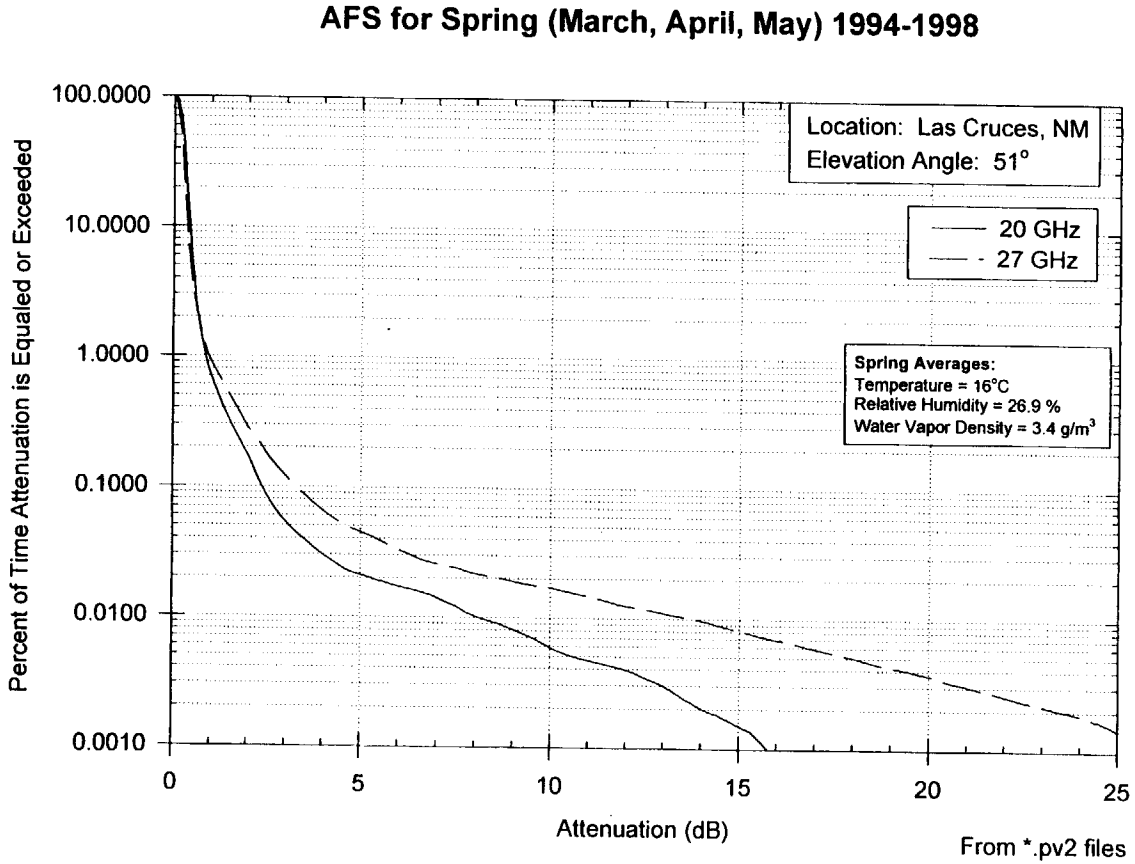
Five Year Spring AFS Statistics



- Historical weather data for the New Mexico site: For Spring, the average temperature is 16.9°C and the average relative humidity is 26.3%.

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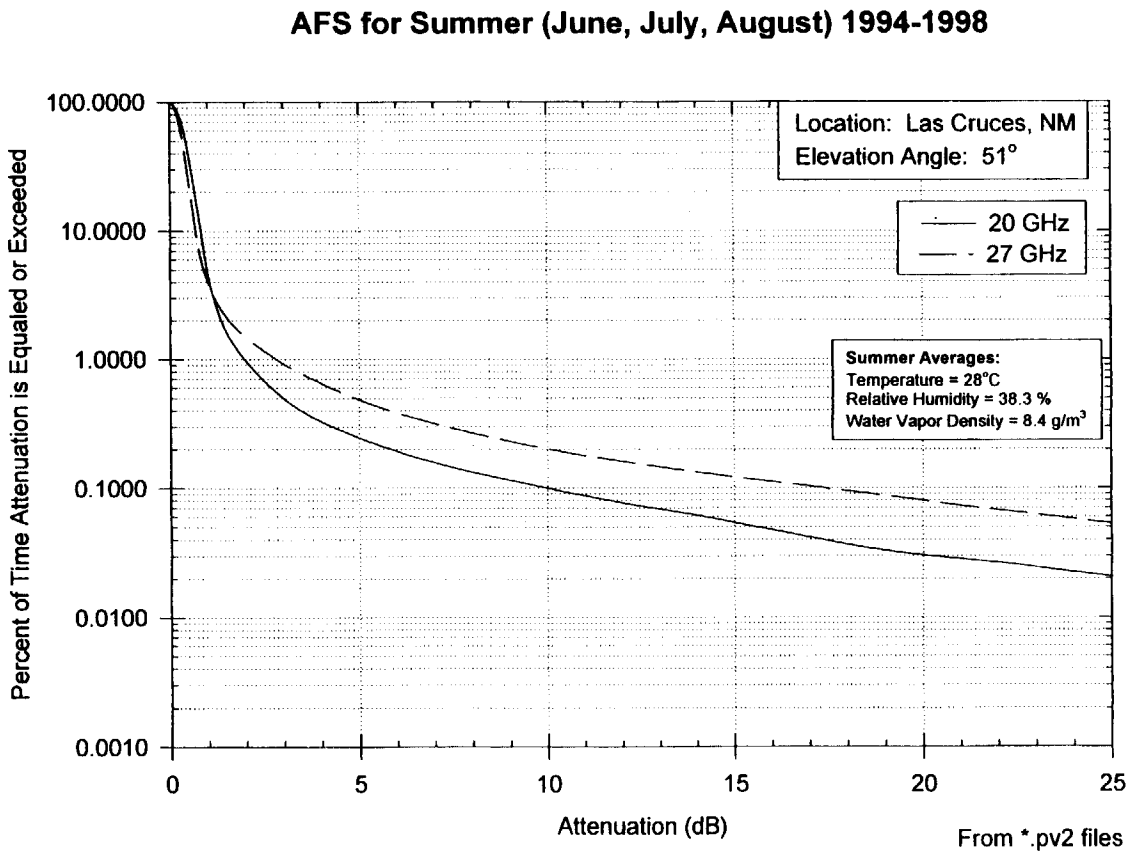
Five Year Summer AFS Statistics



- Historical weather data for the New Mexico site: For Summer, the average temperature is 27°C and the average relative humidity is 41.3%.

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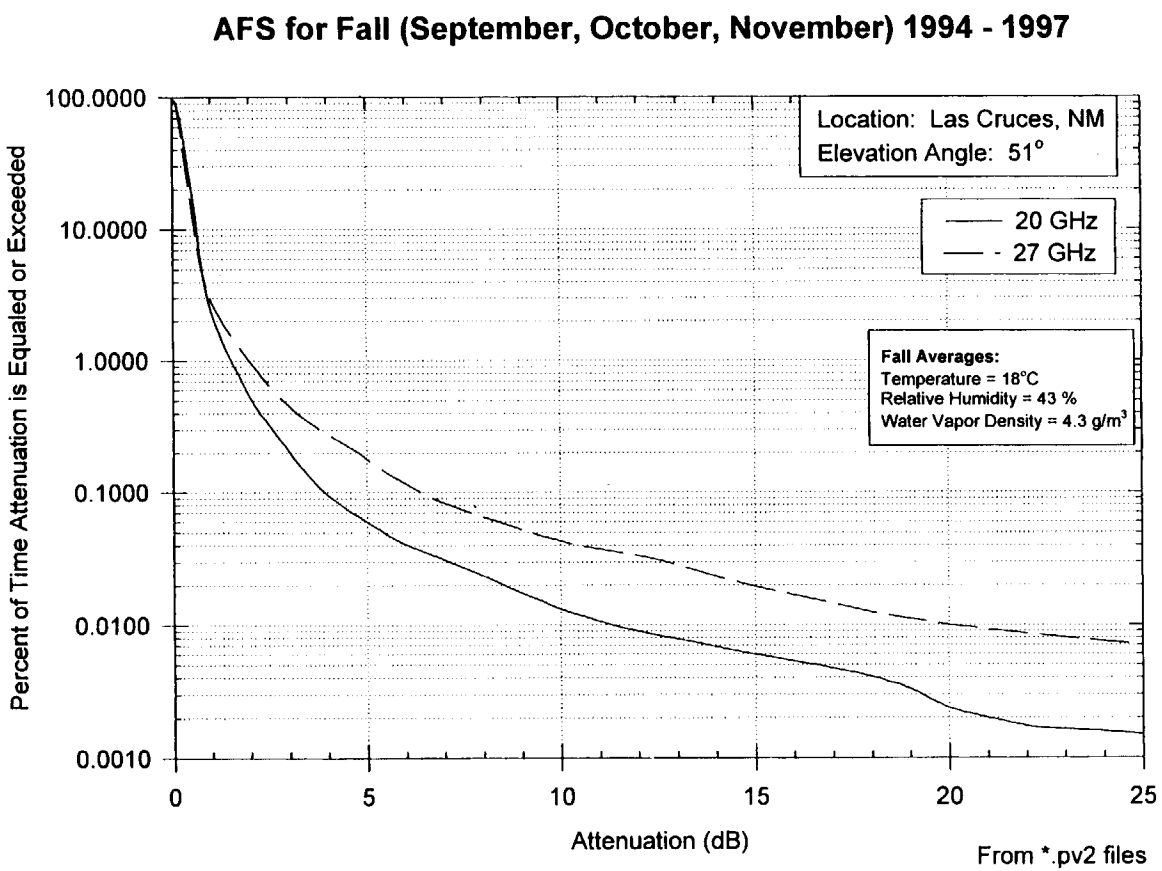
Four Year Fall AFS Statistics



- Historical weather data for the New Mexico site: For Fall, the average temperature is 17.7°C and the average relative humidity is 42.3%.

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Summary of Seasonal Statistics

- **Measured Link Performance for 12/93-8/98 (*.pv2):**

		20.2 GHz		27.5 GHz	
	% Availability	99.9	99.99	99.9	99.99
	% Outage Time	0.1	0.01	0.1	0.01
Attenuation	Winter(5-yr)	3.0 dB	5.5 dB	4.4 dB	7.3 dB
	Spring(5-yr)	2.4 dB	8.0 dB	3.3 dB	13.3 dB
	Summer(5-Yr)	10.0 dB	>25.0 dB	17.3 dB	>25.0 dB
	Fall(4-yr)	3.9 dB	11.2 dB	6.4 dB	20.0 dB

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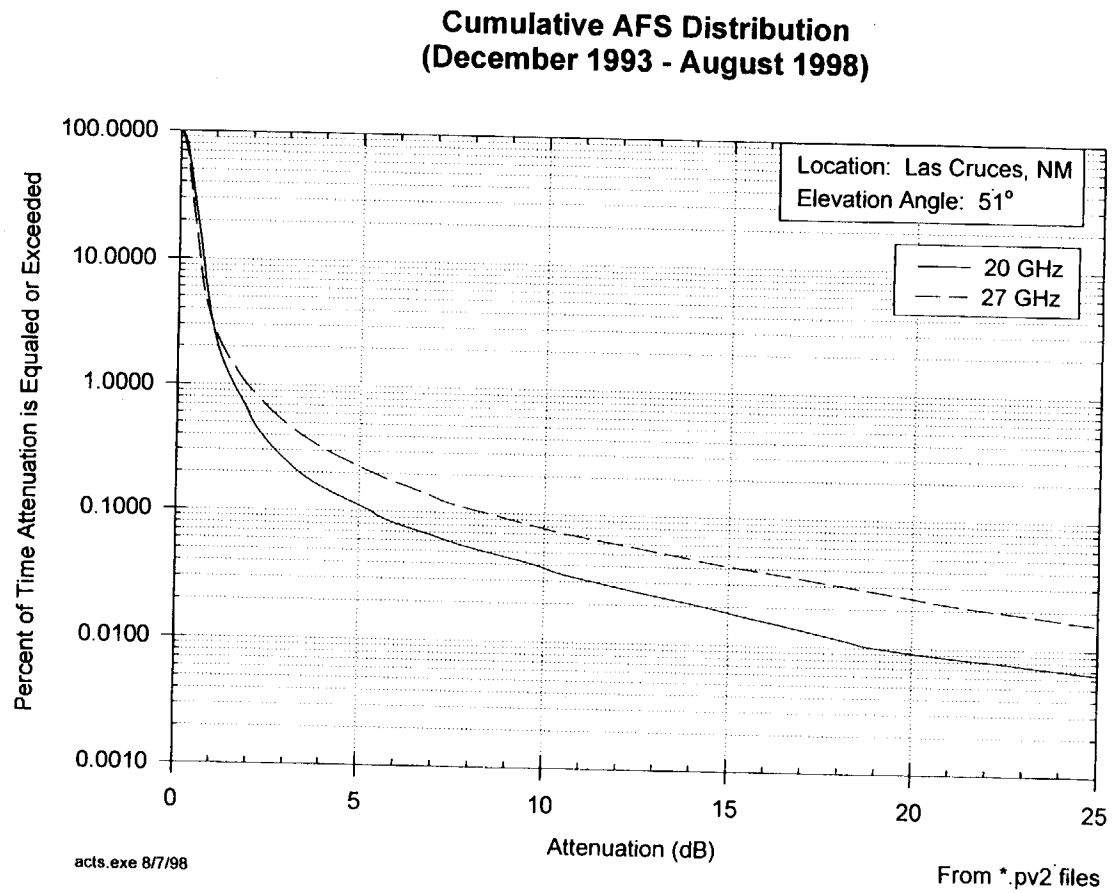
57 Month Cumulative Attenuation wrt Free Space(AFS)



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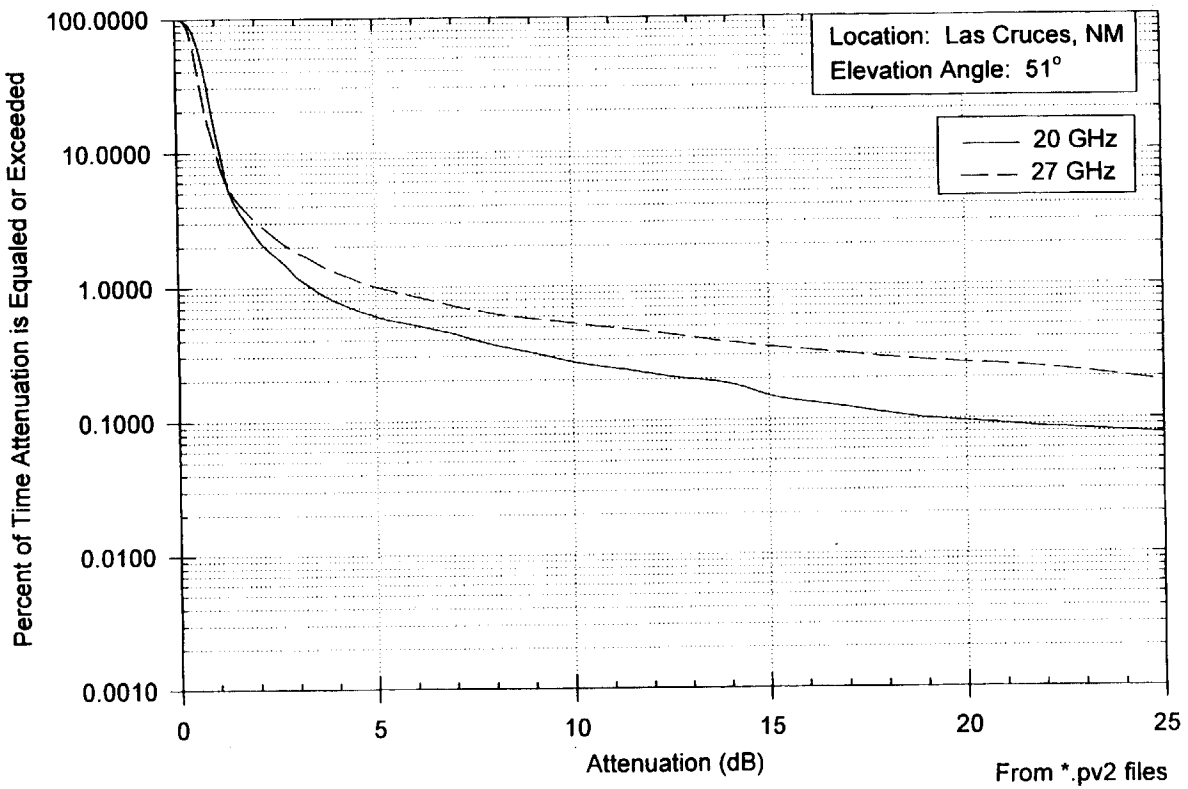
Actual Worst Month: July 1997 Attenuation wrt Free Space (AFS)



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New Mexico ACTS Statistics Summary

- **Seasonal Statistics**
  - ➢ Majority of Large Fades occur in summer months.
- **Rain attenuation model prediction comparisons**
  - ➢ All the rain models match the empirical data fairly well
  - ➢ Adding wet surface effects to the rain attenuation models improves the models significantly.
- **Worst actual month (in 57 months): July 1997**

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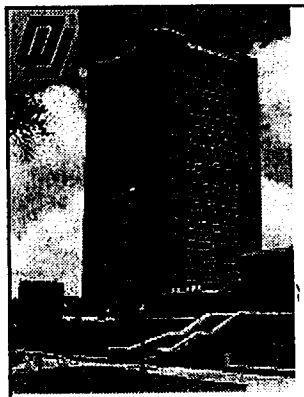
STel Future ACTS Activities

- Complete 5 year cumulative distributions from *.pv0 preprocessing
- Complete 5 year cumulative distributions from *.pv2 preprocessing
- Complete the 5 year final report



ACTS Propagation Studies in Oklahoma

Xuhe Wang

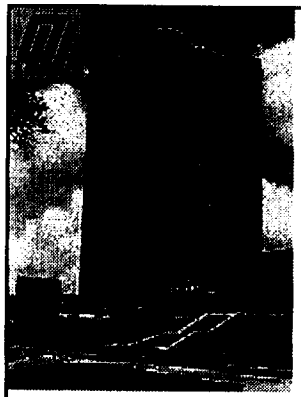
Robert K. Crane

School of Meteorology, University of Oklahoma

APSW XI

Oklahoma City, OK

October 22-23, 1998

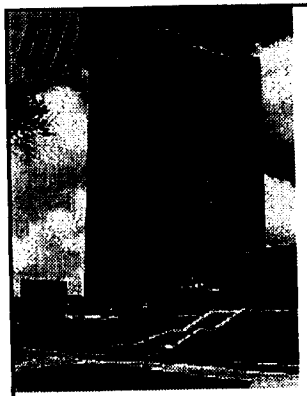


Outline

- OK APT Status - Terminal Update
- Reprocessing 4-year OK, MD, BC data
  - ACTS04.XLS Excel Macros
  - OK ACTS Home Page Update
    - HDR File Archives Status

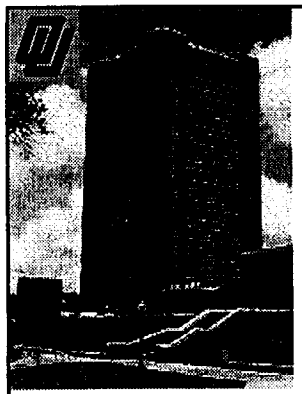
OK APT Status -Terminal Update

- Replaced ethernet card with ZIP (parallel port) drive on 11/14/97, but failed. Ethernet card was re-installed on 11/30/97. Since then lots of 1-2 seconds gaps in every day data. The problem was fixed by replacing the PC's mother board and all the cards on March 24, 1998. ZIP drive was also installed.
- "Lost default drive" bug in dacs.exe (TSR) was found during testing ZIP drive.
- Fiber optics modem power failed on 6/17/98 - 7/16/98. Many system crashes and data lost during that time period.
- APT system is now working smoothly except WWV card clock jumping problem still remains.

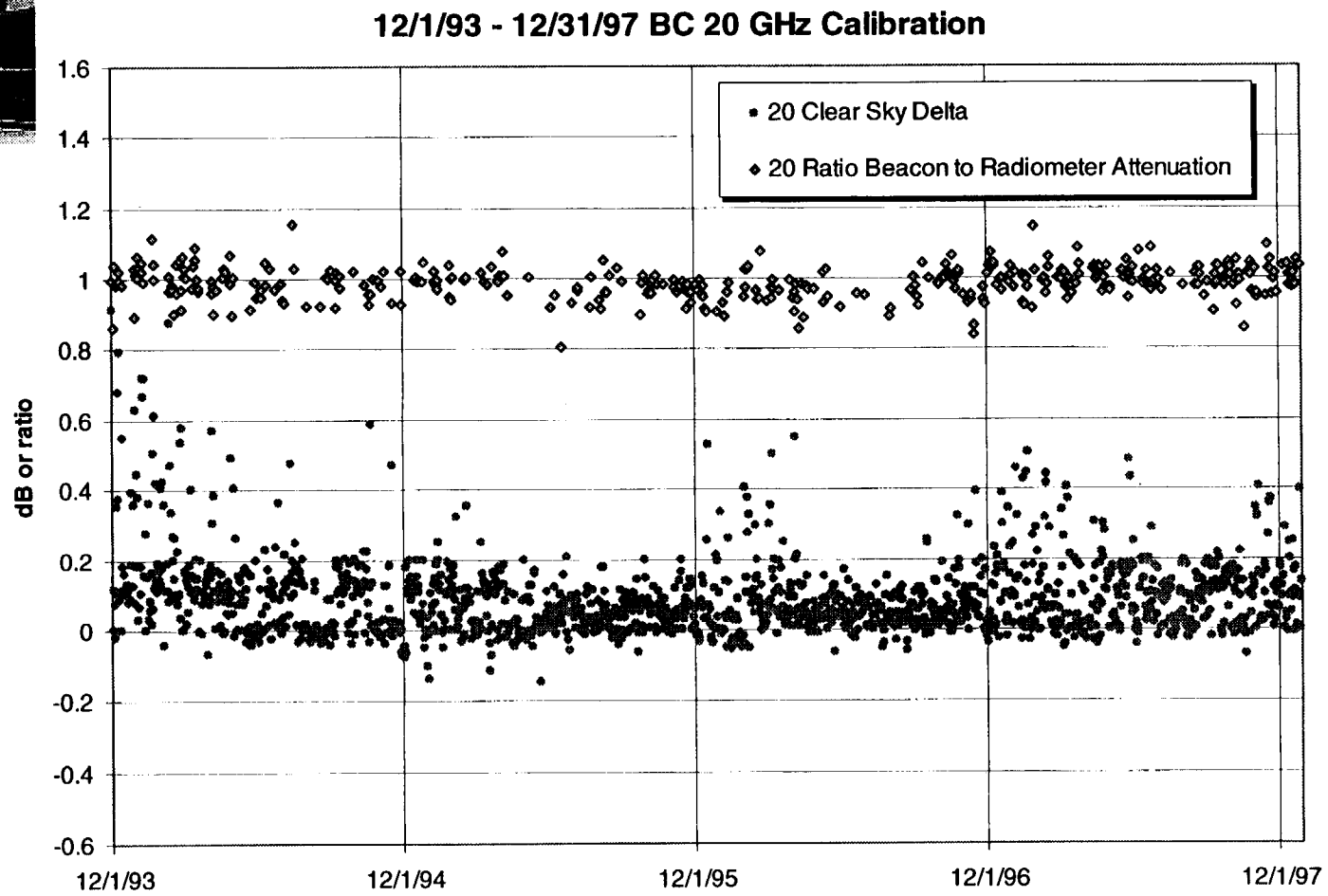


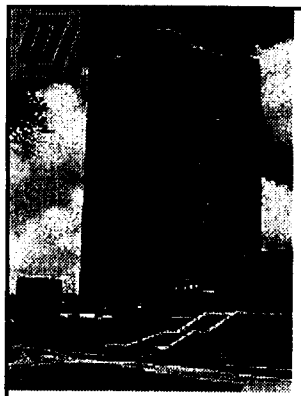
Reprocessing 4-year OK, MD, BC Data

- A new 333MHz PentiumII PC was used in reprocessing, which led to find that ACTSPP need updated to run on a fast PC.
- Weather events, system and operational faults were inserted into .LOG files, and marked bad if necessary. Snow events and rain gauge noises were marked bad in .LOG files.
- Calibration constants were re-adjusted for each site. For BC data calibration was done on a daily basis.
- A radiometer swapping problem were found in ACTSPP program during reprocessing MD data. MD data were then reprocessed second time with the new updated ACTSPP.
- NCDC surface data were used in reprocessing BC and MD data. Oklahoma Mesonet surface data were used in reprocessing OK data.

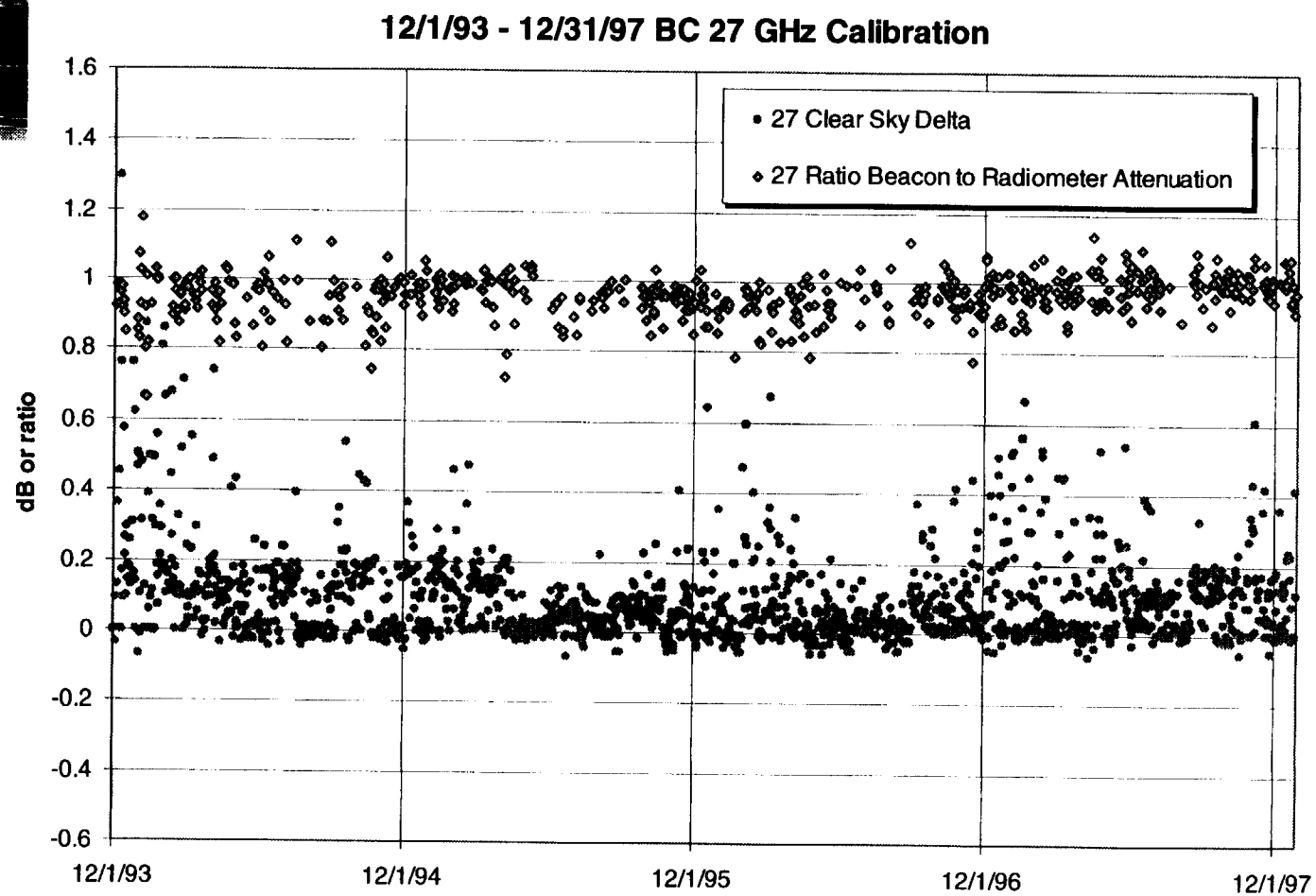


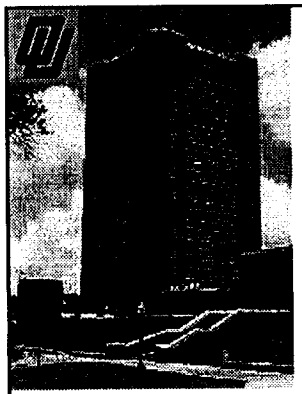
Reprocessing 4-year OK, MD, BC Data



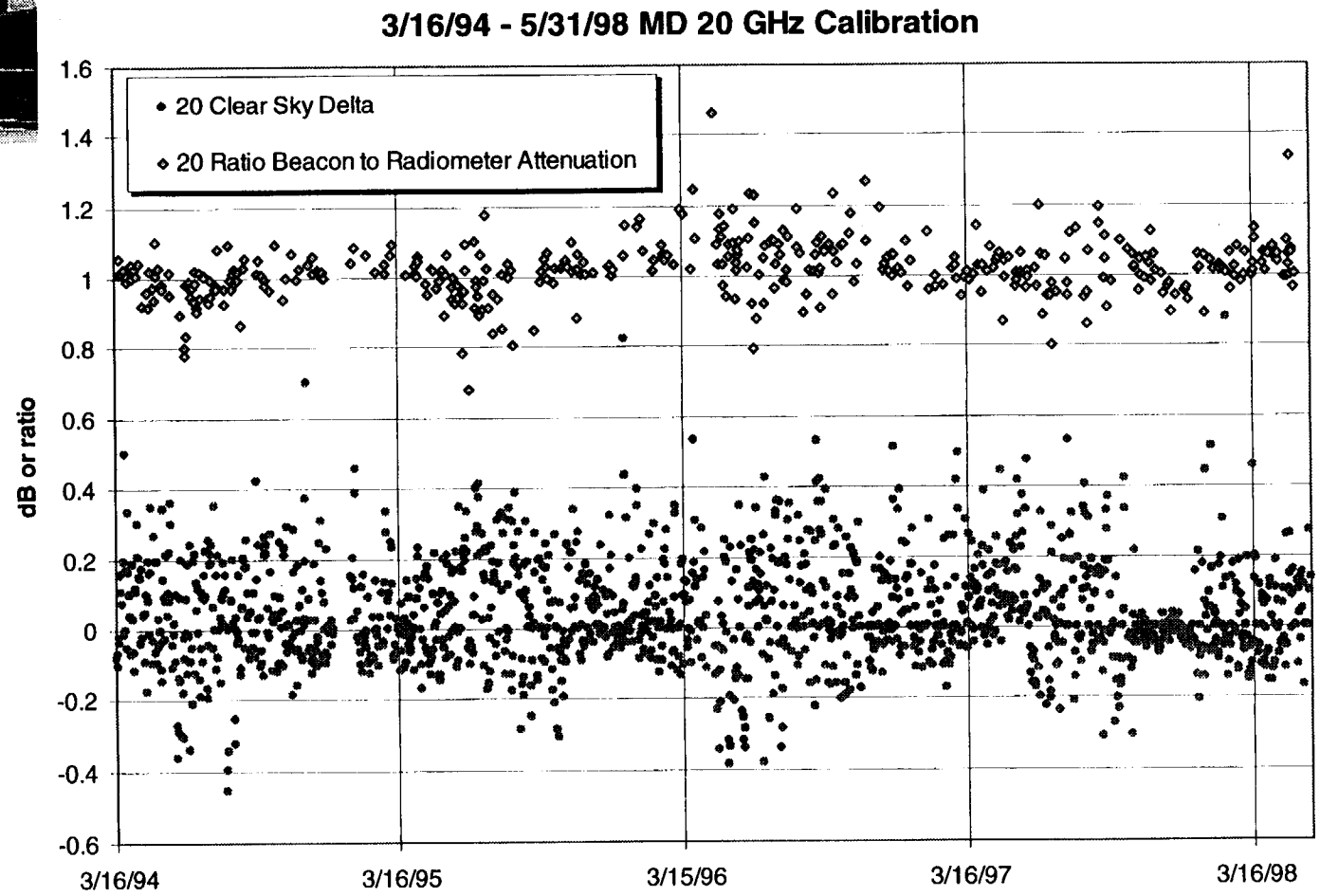


Reprocessing 4-year OK, MD, BC Data

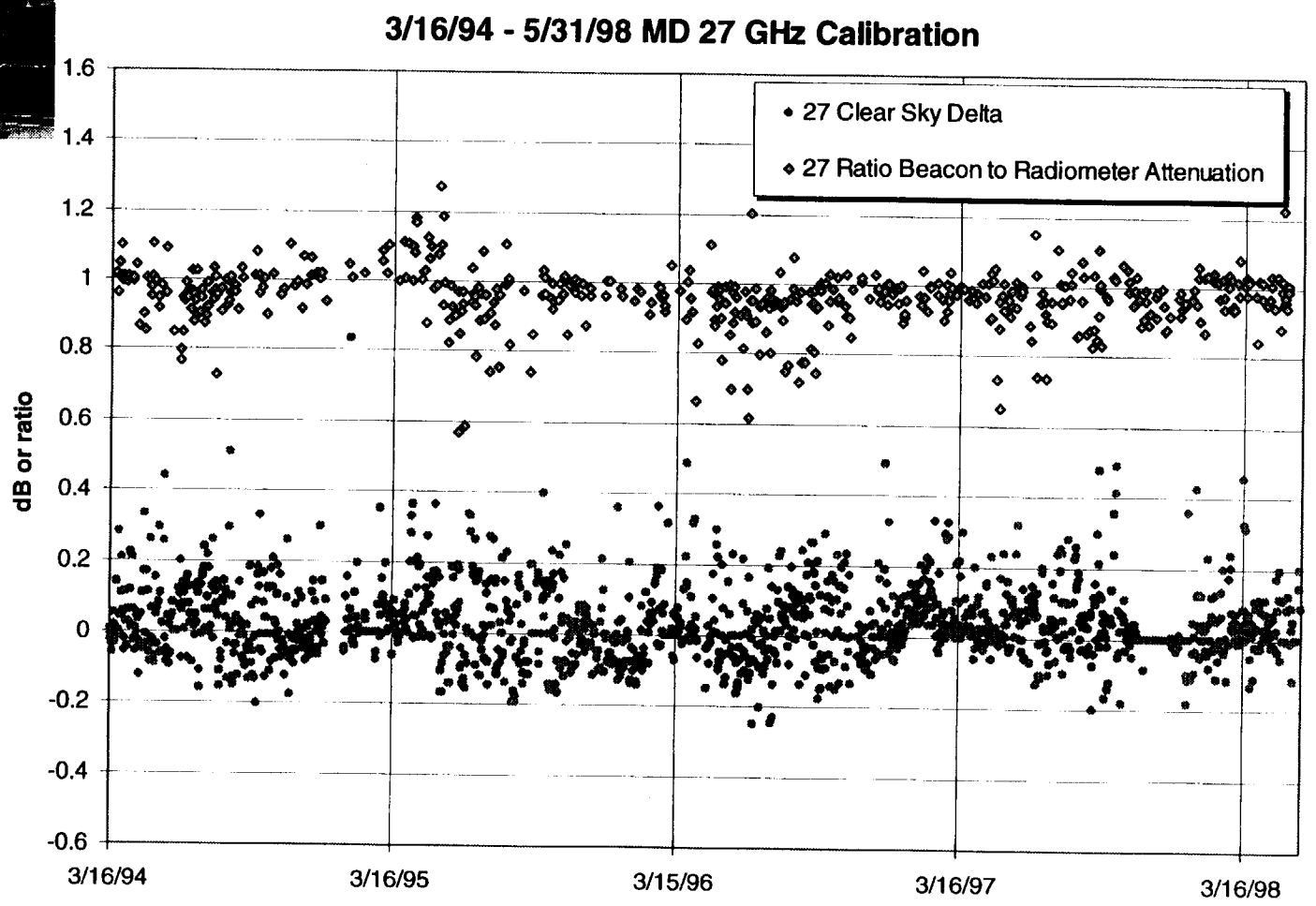


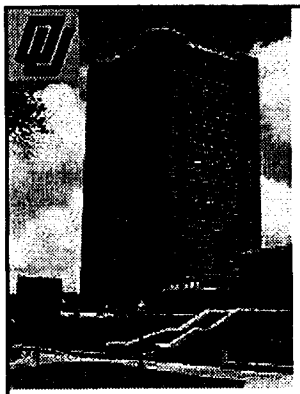


Reprocessing 4-year OK, MD, BC Data

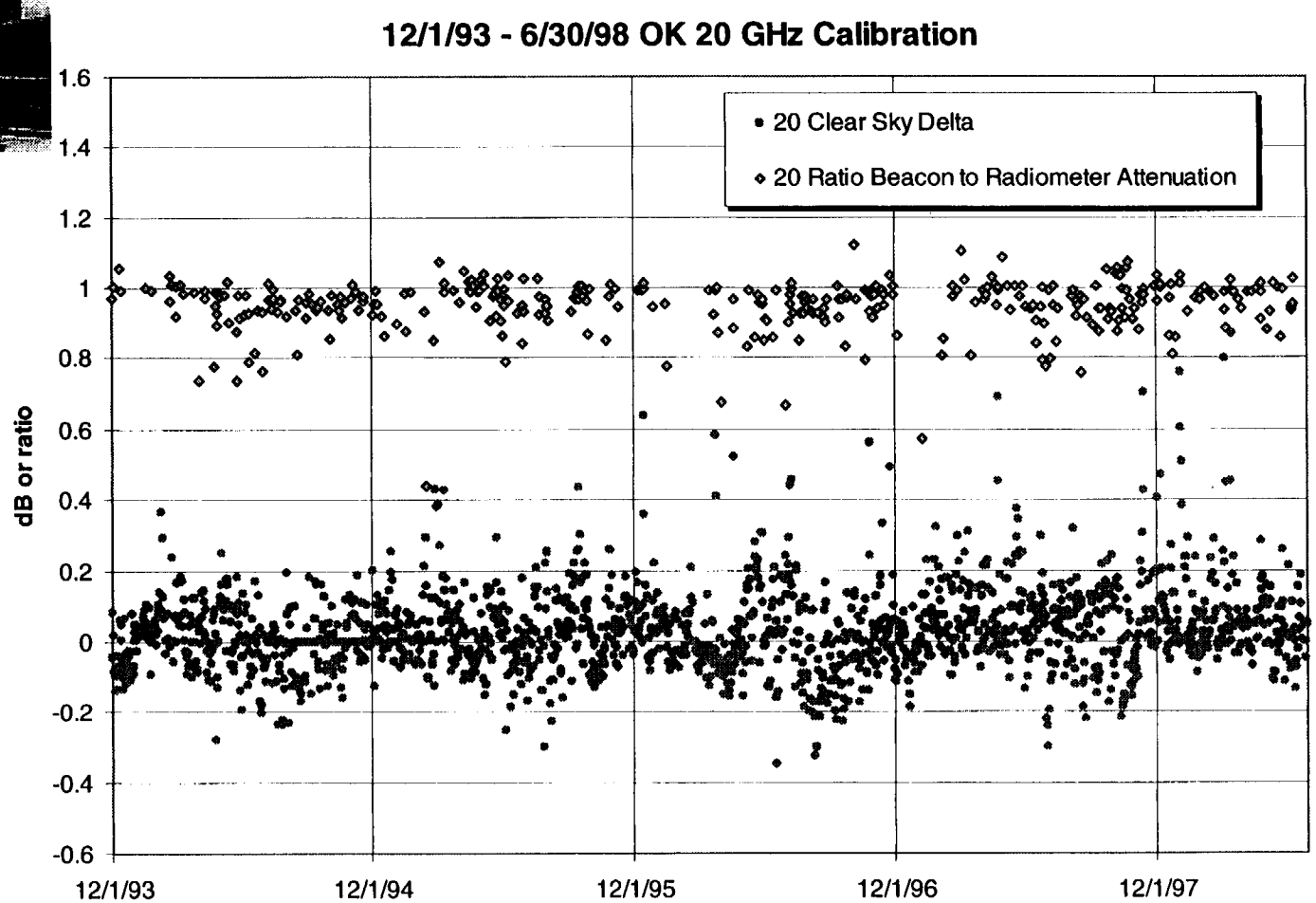


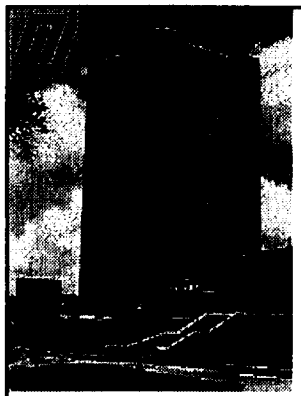
Reprocessing 4-year OK, MD, BC Data



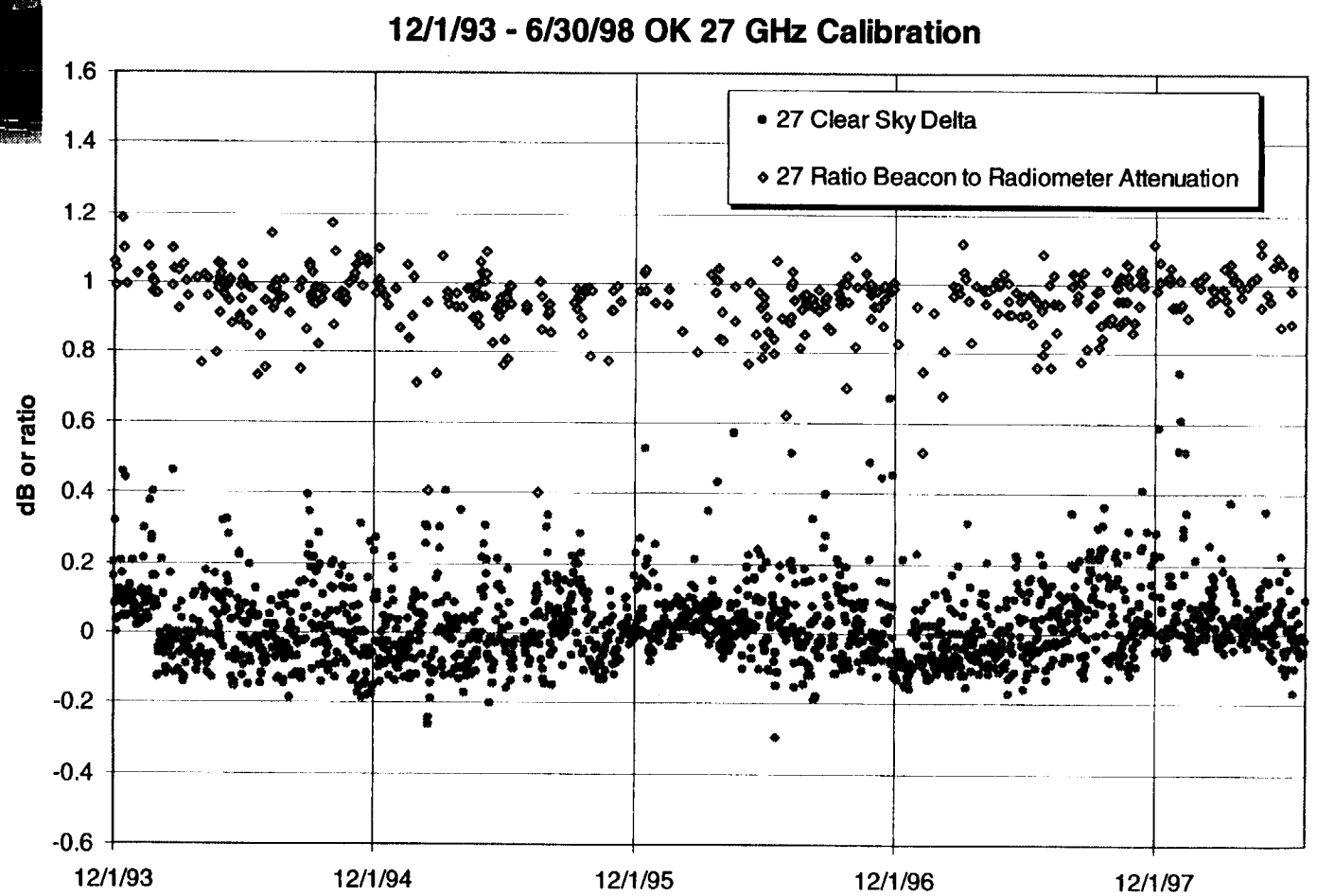


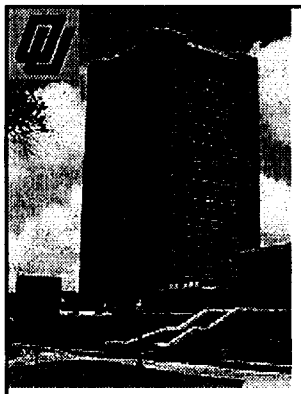
Reprocessing 4-year OK, MD, BC Data





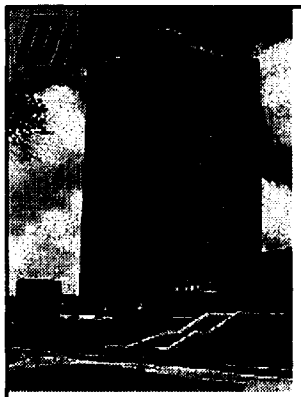
Reprocessing 4-year OK, MD, BC Data



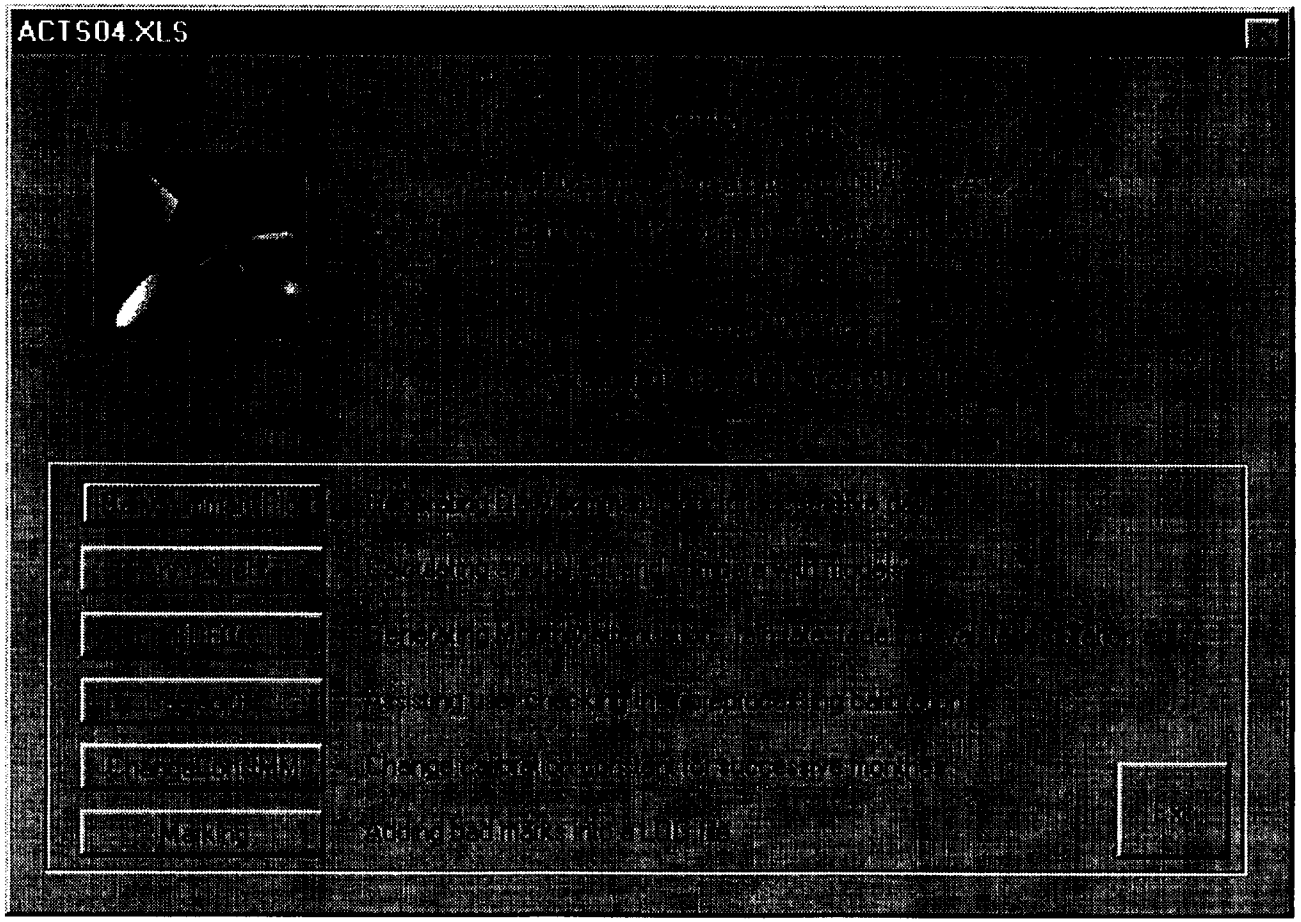


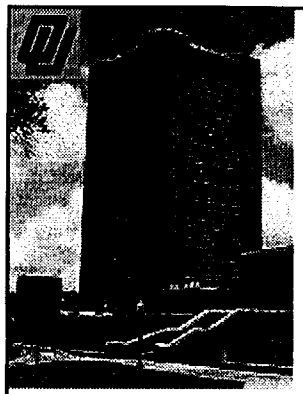
ACTS04.XLS Excel Macros

- New user interface and more error prevention codes.
- Two new macros added.
  - ChangeConstMM
  - Marking
- Annual_edf macros now can compare the calculated edfs with attenuation models (need first install Attenuation Model Excel Add-in, which can be found at our web site).
- Current version can not run in Excel 97. Still working on new version.
- Testing version can be found in our ftp address or web page. Comments and suggestions are welcome.

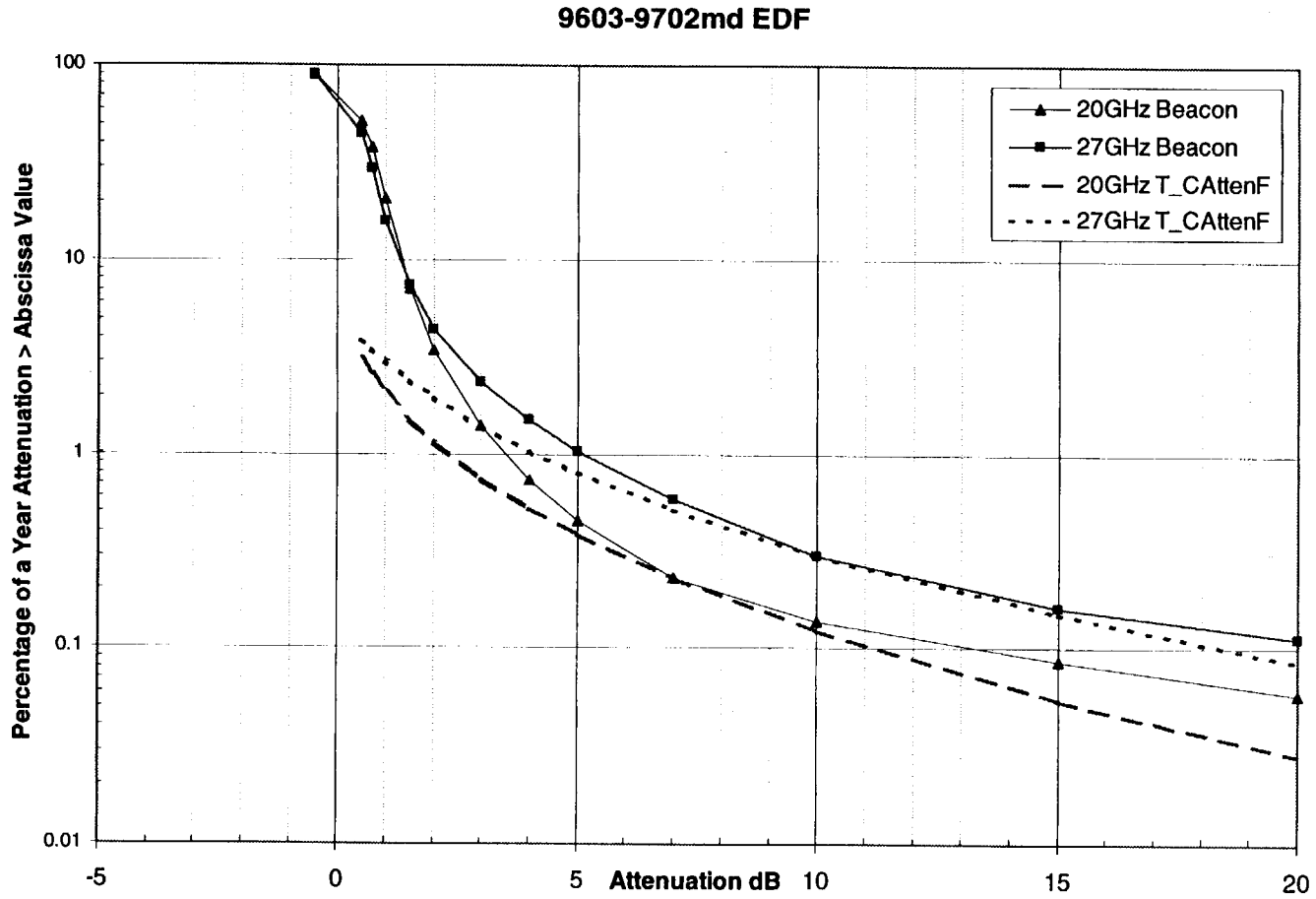


ACTS04.XLS Excel Macros





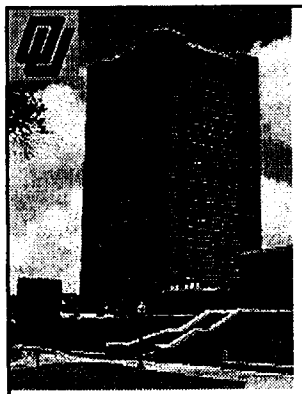
ACTS04.XLS Excel Macros



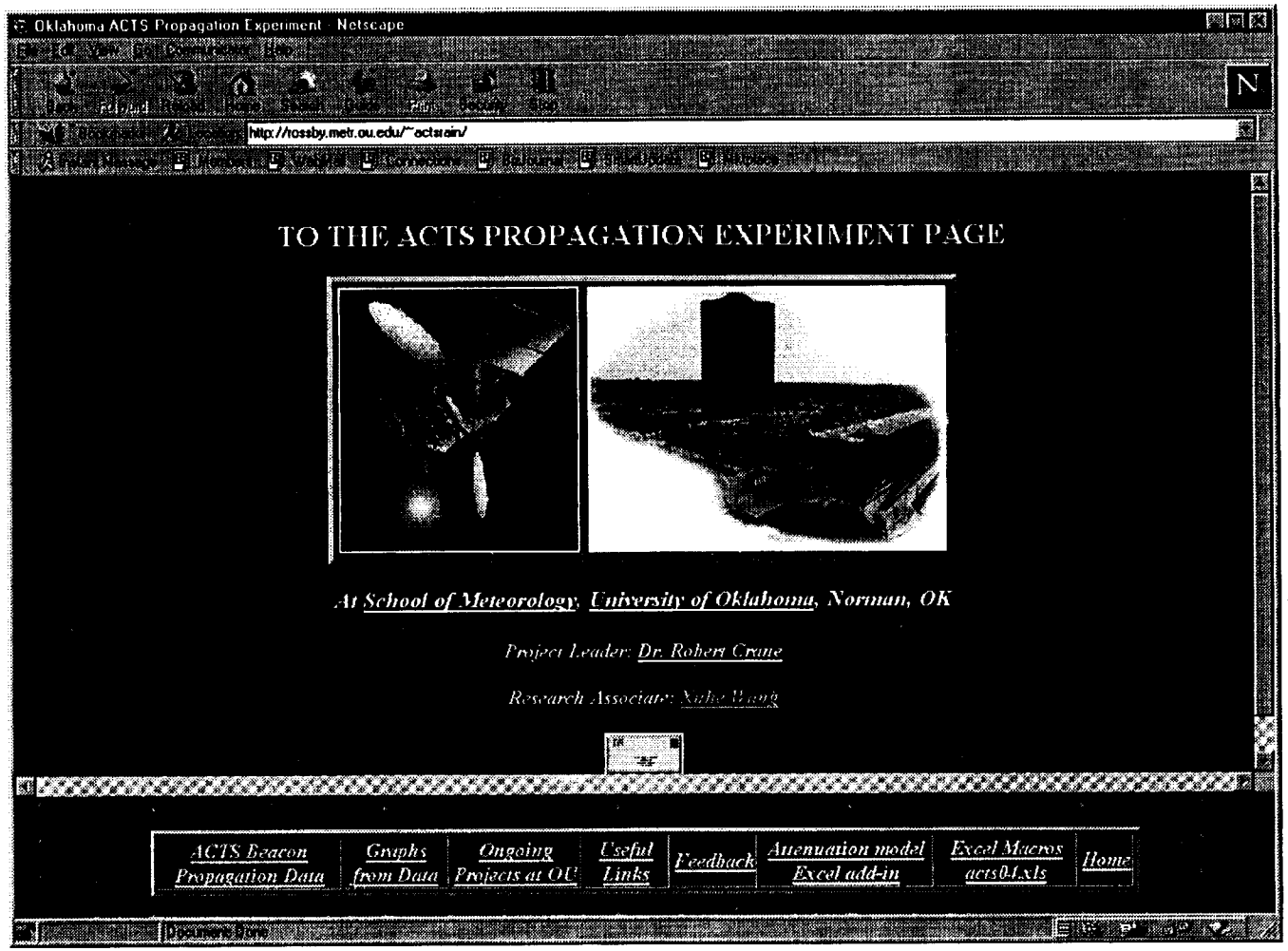
Oklahoma ACTS Home Page Update

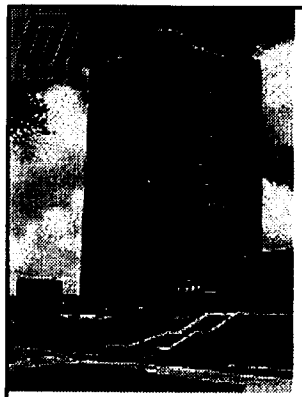
- http://rossby.metr.ou.edu/~actsrain/

- The page now has a new look, and many useful links about Ka-band SatCom.
- A text readme file has been added to Attenuation Model Excel Add-in page, which explains how to use the add-in in more detail.
- A new page - Excel Macros acts04.xls was added. User can get the test version of the macros from there.
- The reprocessed 4-year ACTS propagation data from 7 sites will soon replace the old data and graphs currently kept in the page.



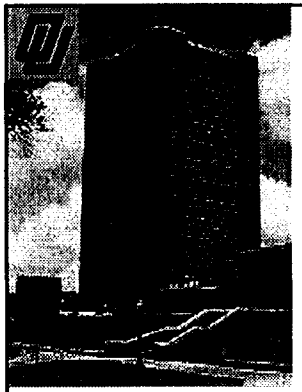
Oklahoma ACTS Home Page Update





HDR File Archives Status

- Current HDR files list
  - AK: 960624-960816, 970607-980630 (16 months)
  - BC: 961021-961023, 980312-980625 (5 months)
  - CO: 960801-960930, 980105-980630 (8 months)
  - FL: 960618-960930 (4 months)
  - MD: 960627-980620 (25 months)
  - NM: 960828-970630, 970801-current (25 months)
  - OK: 960217-current (32 months)
- Experimenters please send your HDR files to Univ. of OK.
- HDR files can be made available on CDs.



Summary of Attenuation Observations for all 7 Sites and Comparison to the Updated Model Predictions

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Xuhe Wang

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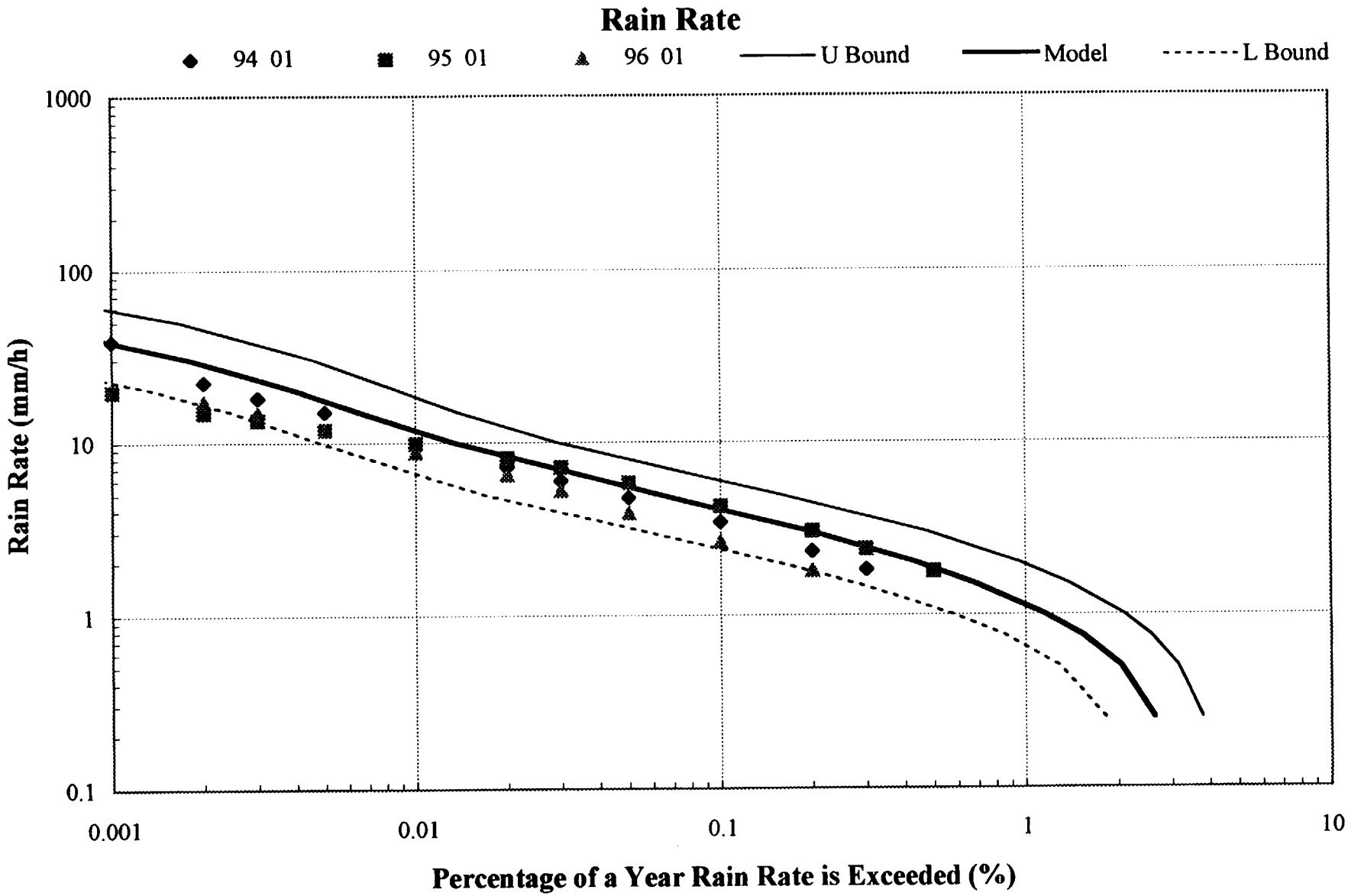
APSW XI

Oklahoma City, OK

October 22-23, 1998

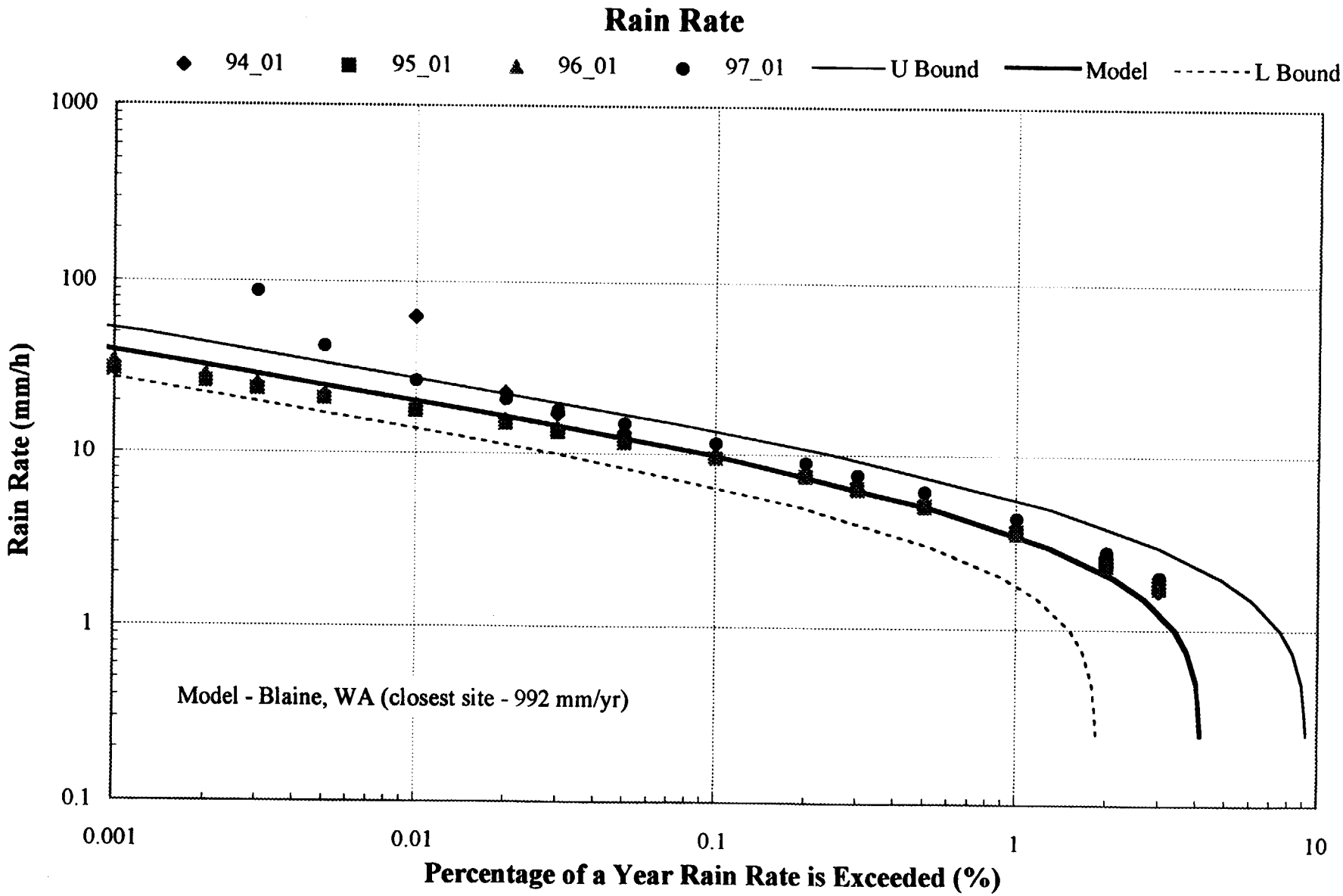
LOCAL MODEL IMPROVEMENTS

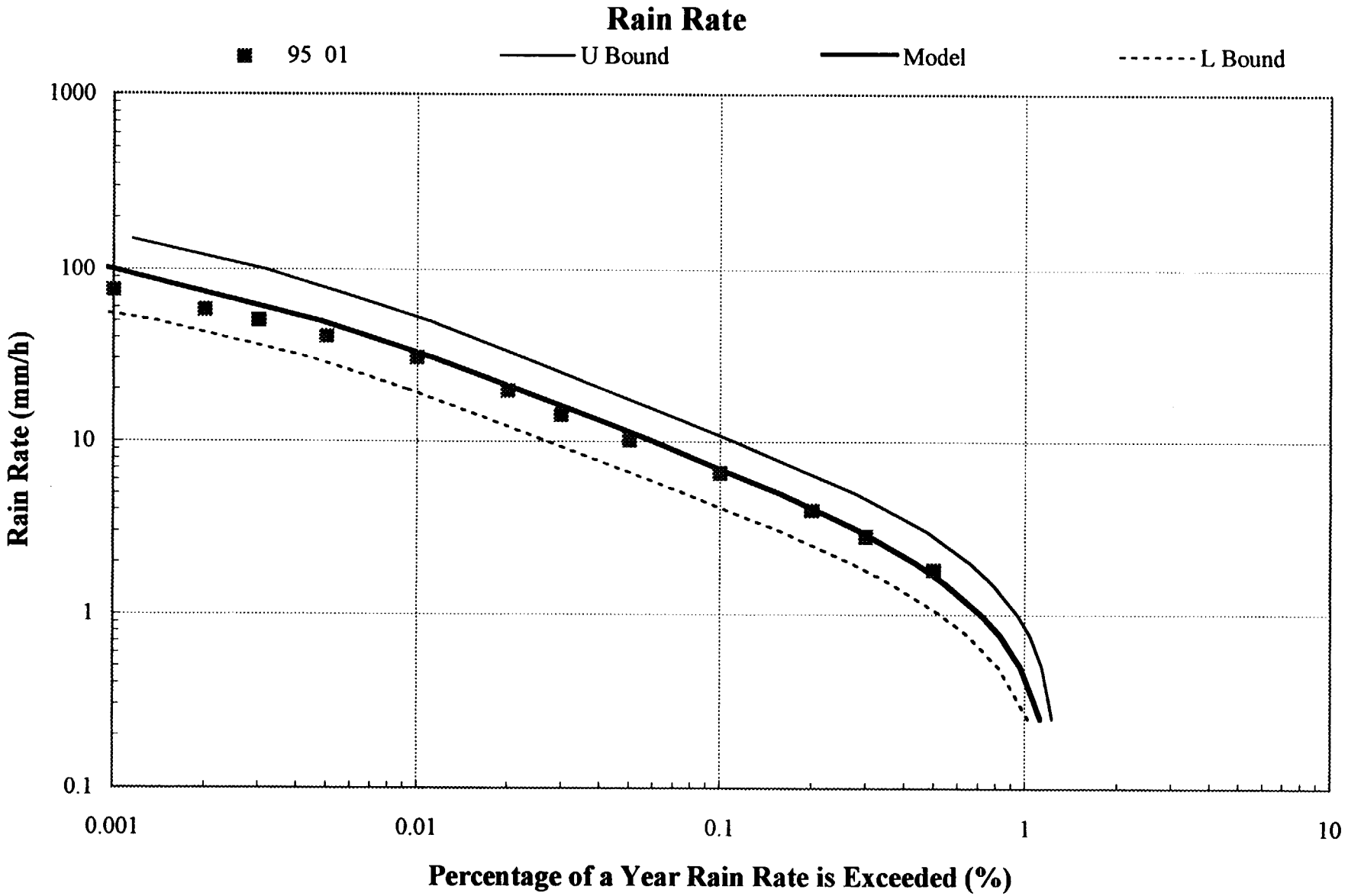
- Model for cell contributions to the rain-rate distribution is now consistent with the model for the cell contribution to attenuation.
- Rain-rate distribution model is revised so local hourly accumulation data can be combined with the cell component from the local model to produce adjusted debris component parameters - used for BC, CO and NM.
- The variability model has been improved using hourly rain accumulation data form each site in the local data base.
- ACTS empirical rain-rain rate distributions are consistent with the updated model predictions (lie within the 90% bounds).
- Corrected ACTS empirical attenuation distributions are consistent with earlier COMSTAR observations at sites where data are available - the corrections are for gaseous absorption and water on the antenna.
- Local or adjusted local attenuation model predictions are consistent with the corrected ACTS empirical attenuation distributions.

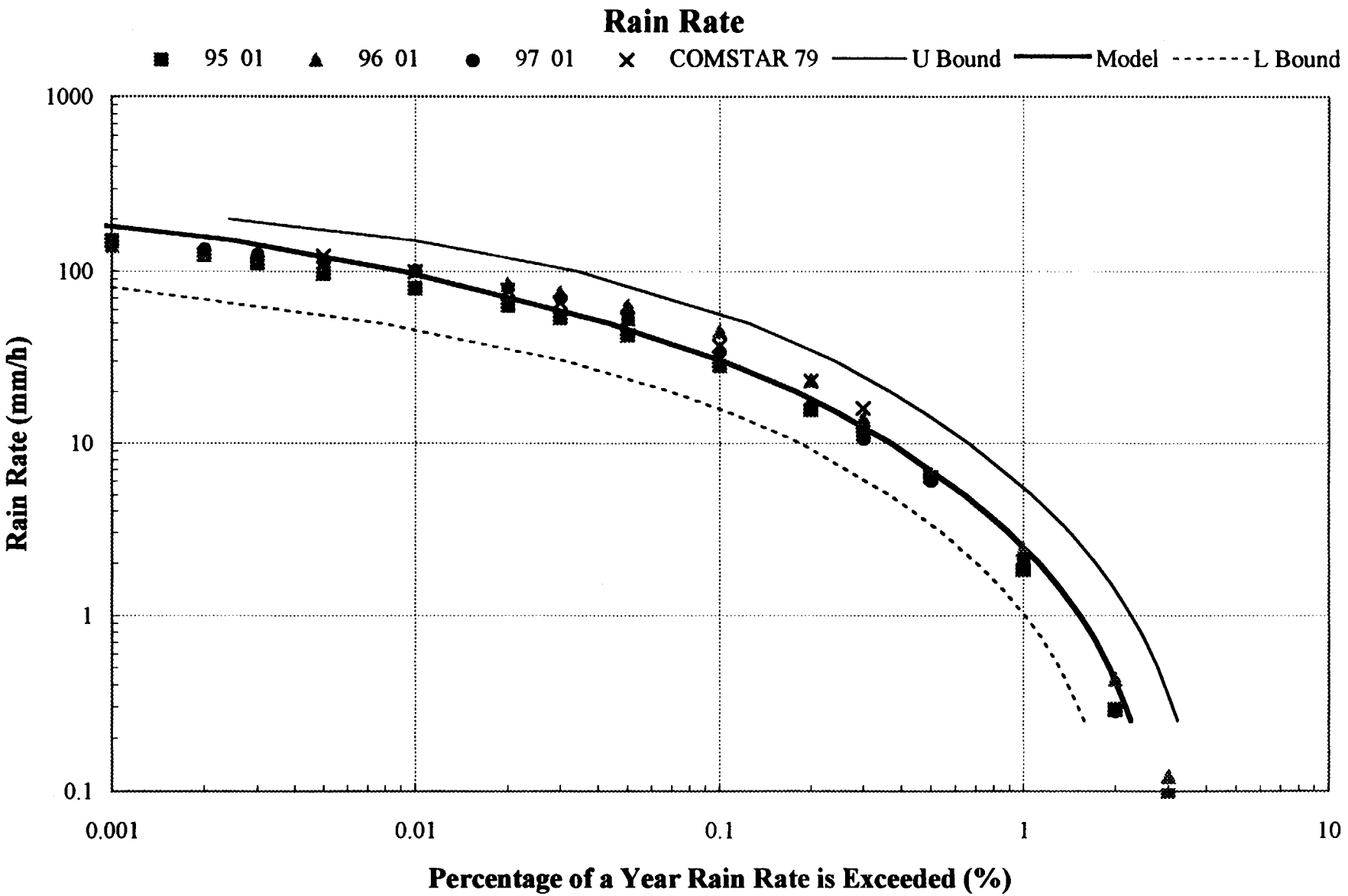

Rain Rate
94 01
95 01
96 01
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)

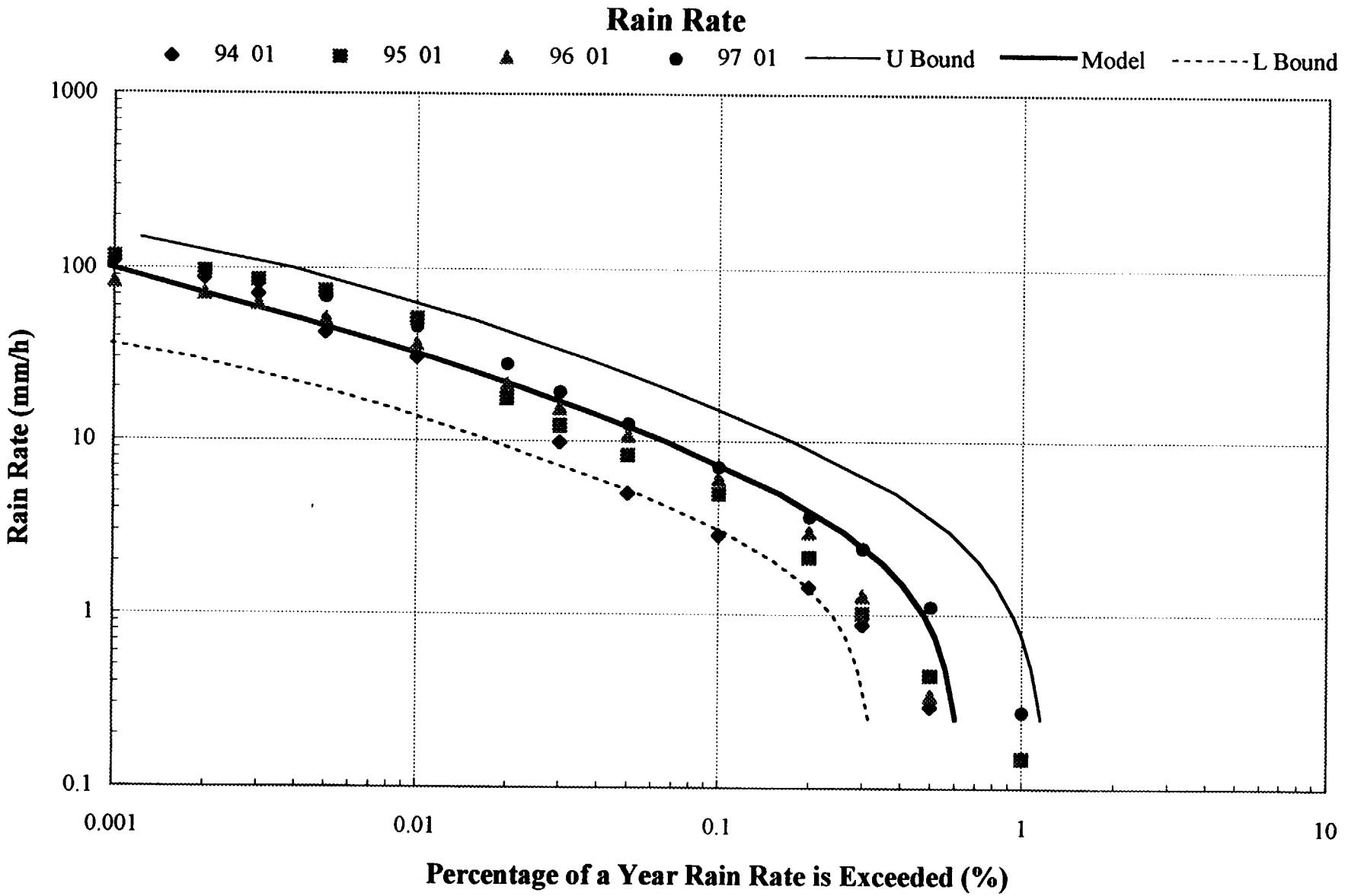
ACTS Propagation Experiment

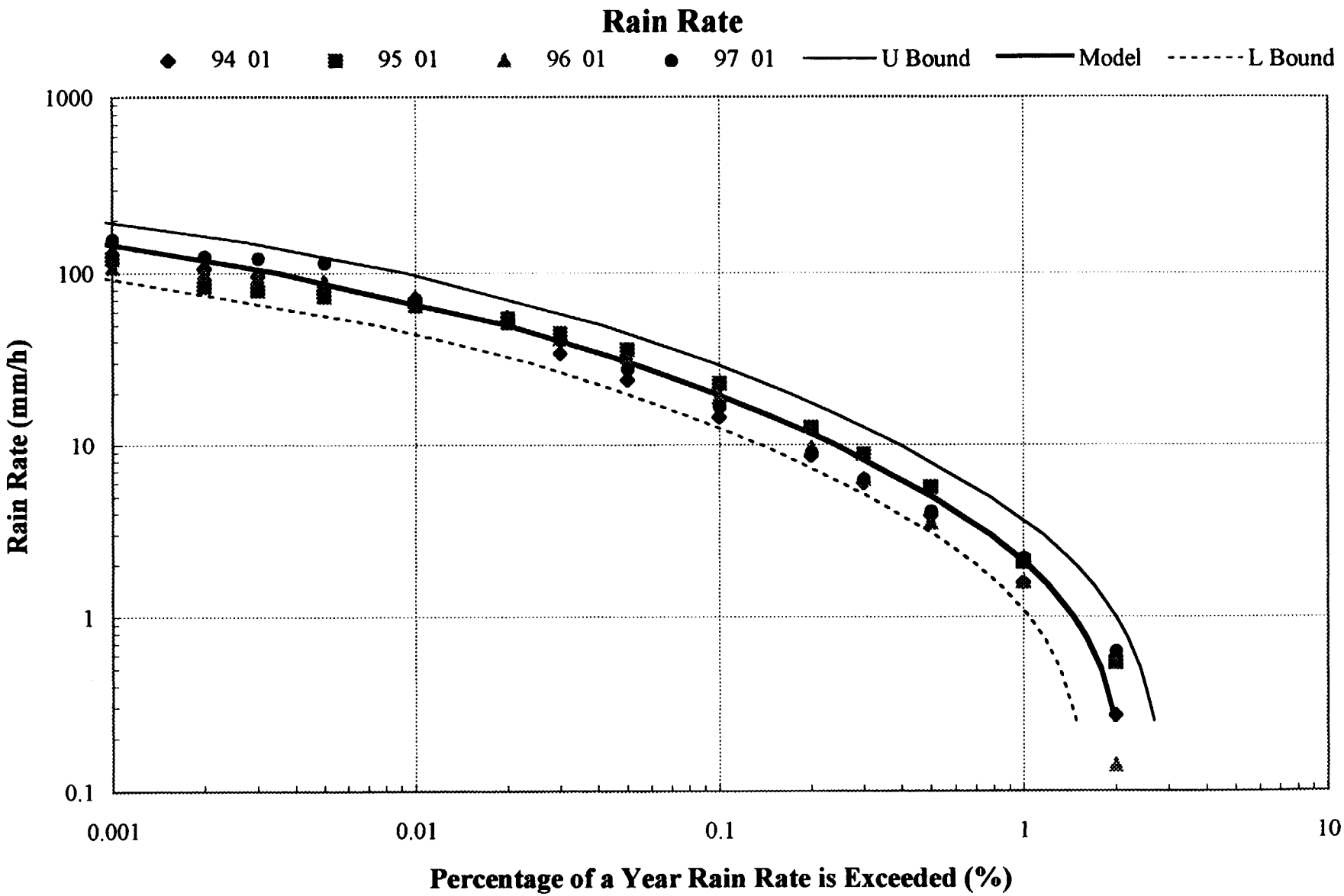
Vancouver, BC

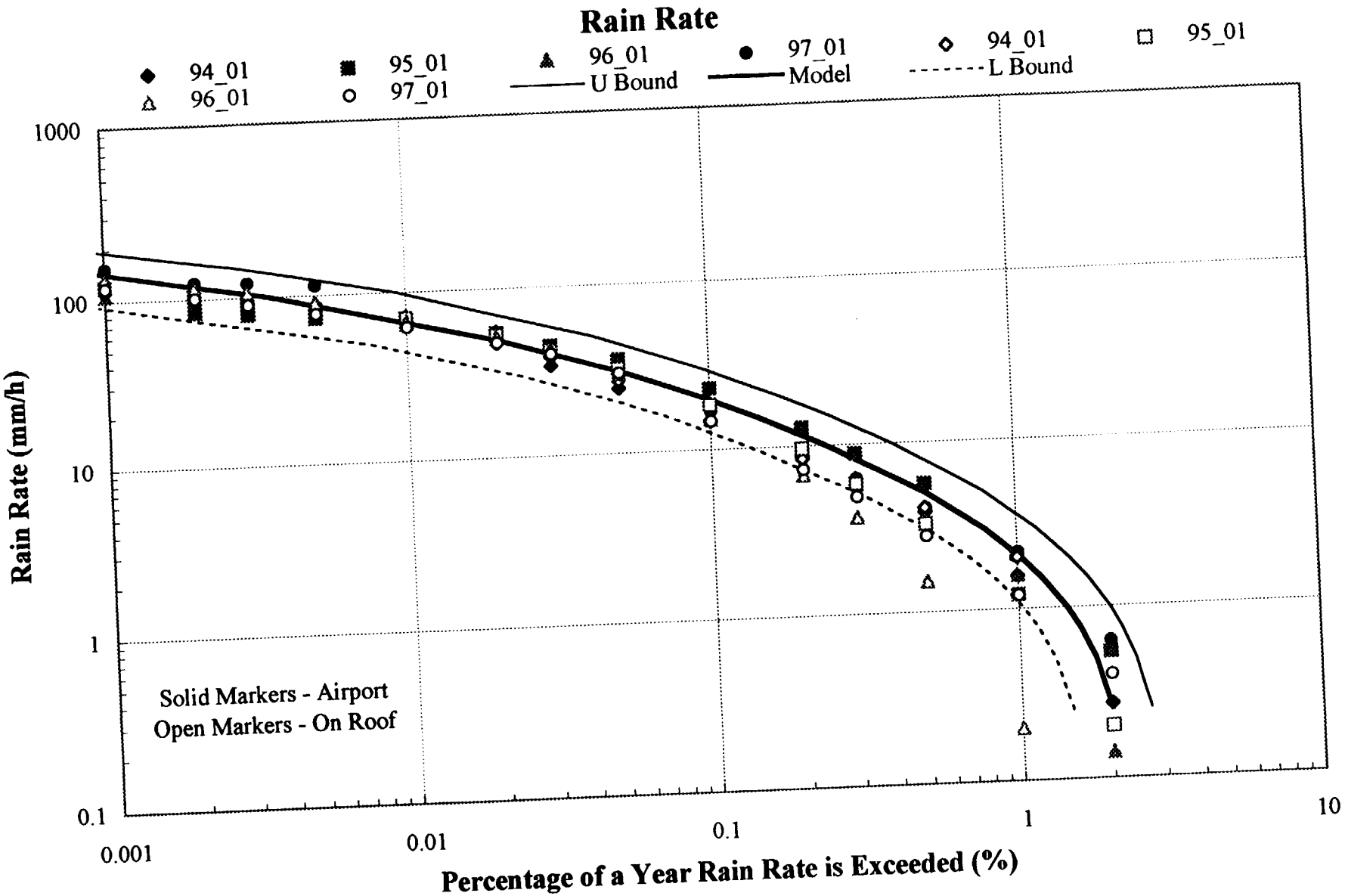



Rain Rate
95 01
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)


Rain Rate
95 01
96 01
97 01
COMSTAR 79
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)

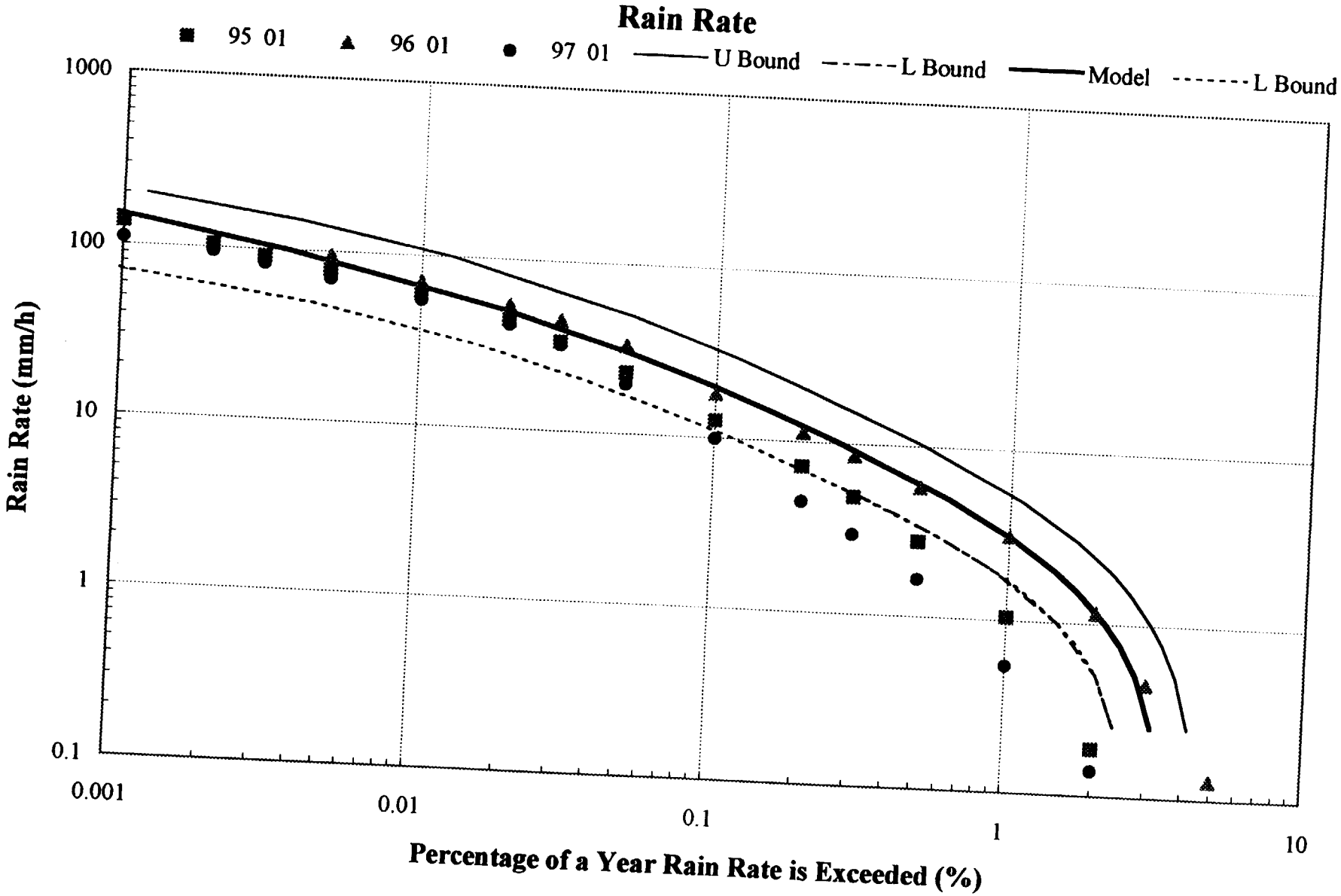

Rain Rate
94 01
95 01
96 01
97 01
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)

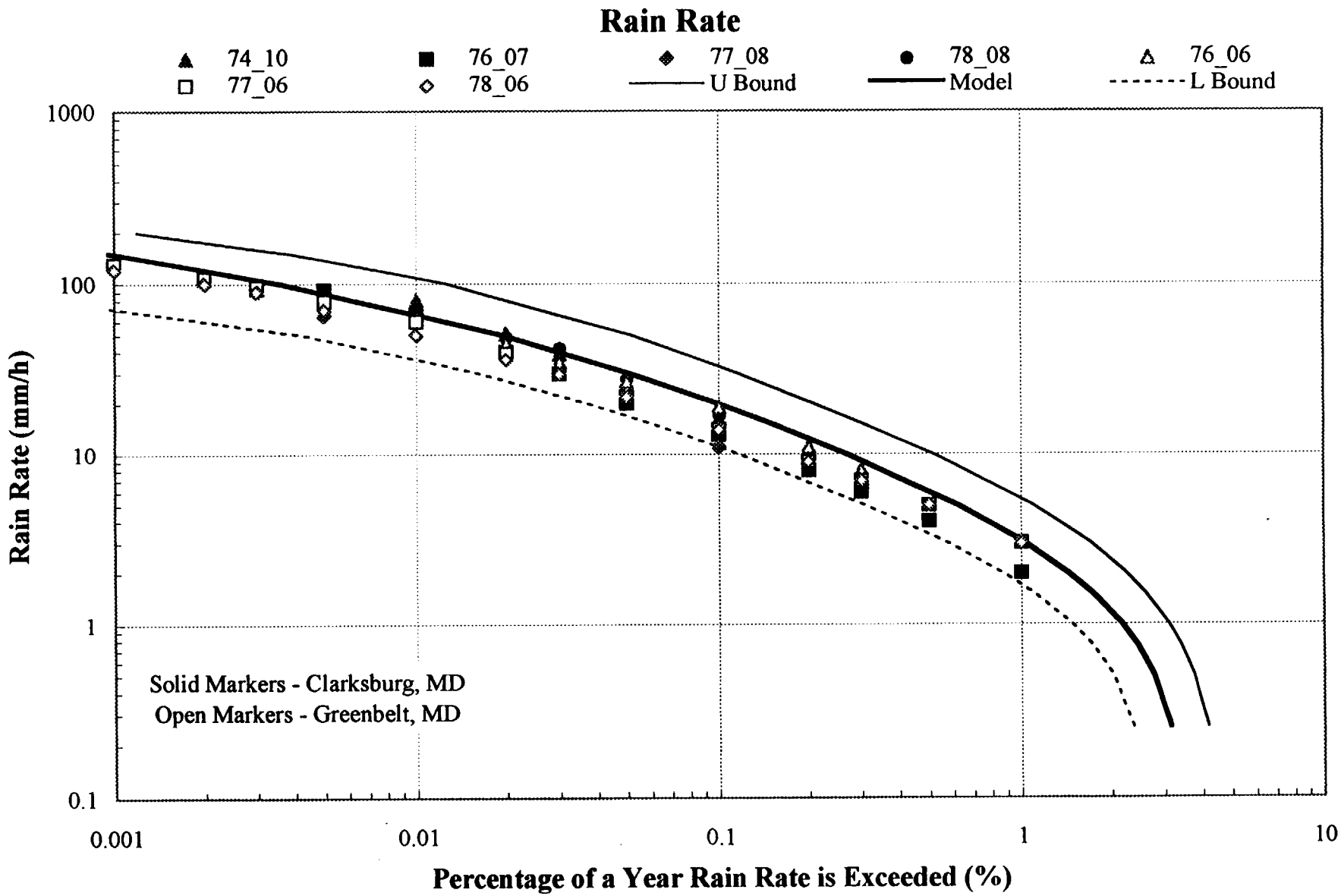

Rain Rate
94 01
95 01
96 01
97 01
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)

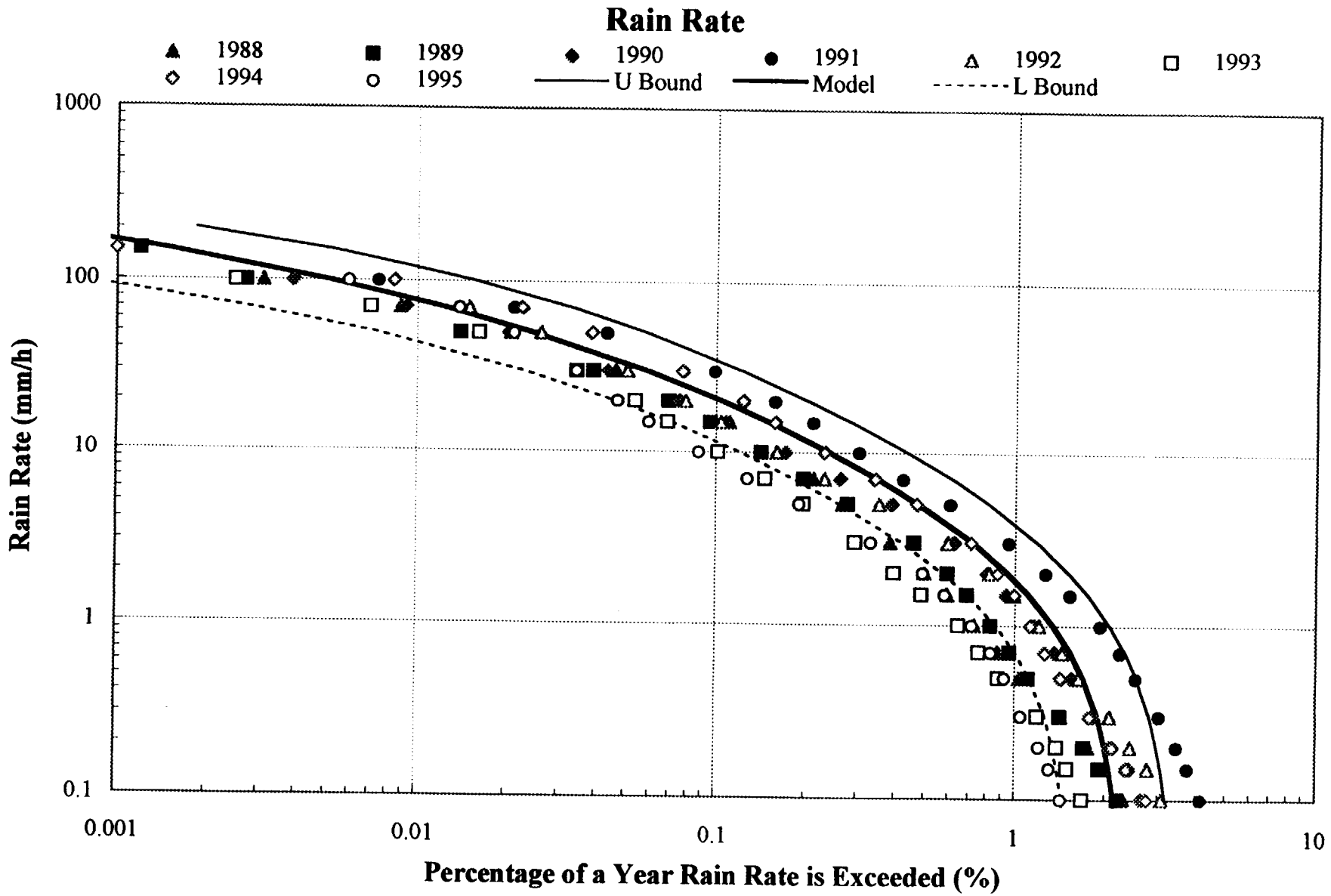

Rain Rate
94_01
95_01
96_01
97_01
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
Solid Markers - Airport
Open Markers - On Roof
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)

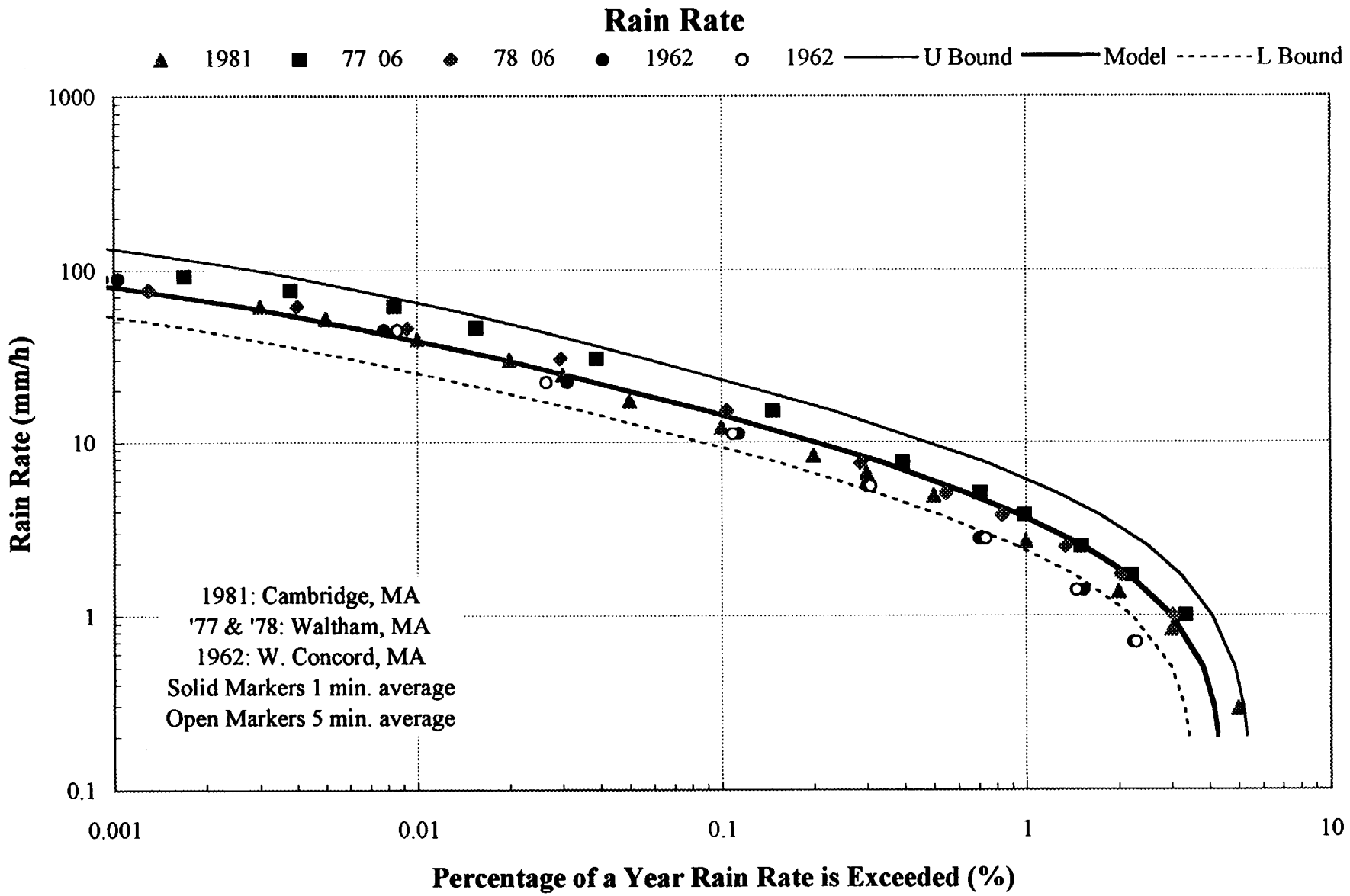
ACTS Propagation Experiment

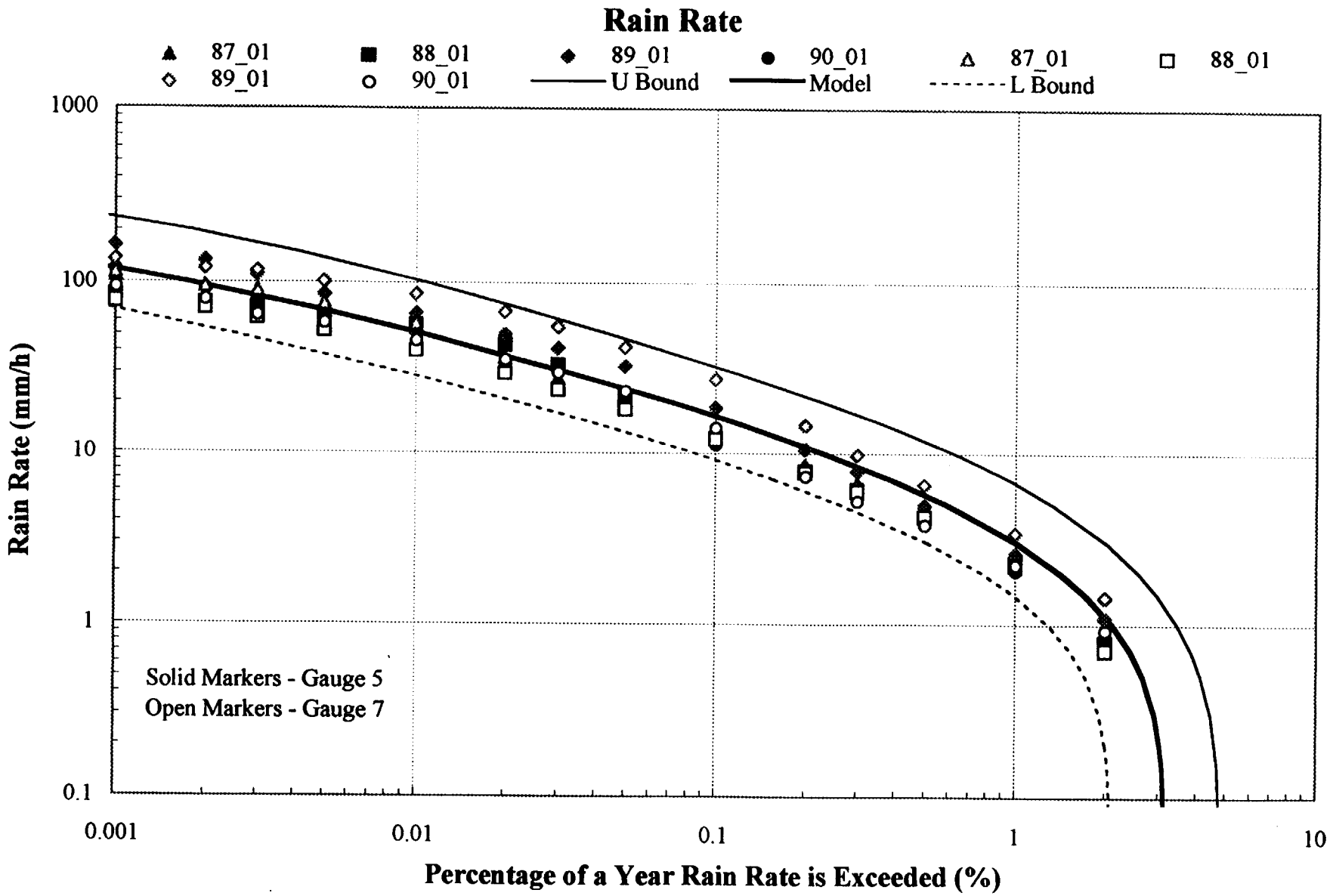
Reston, VA

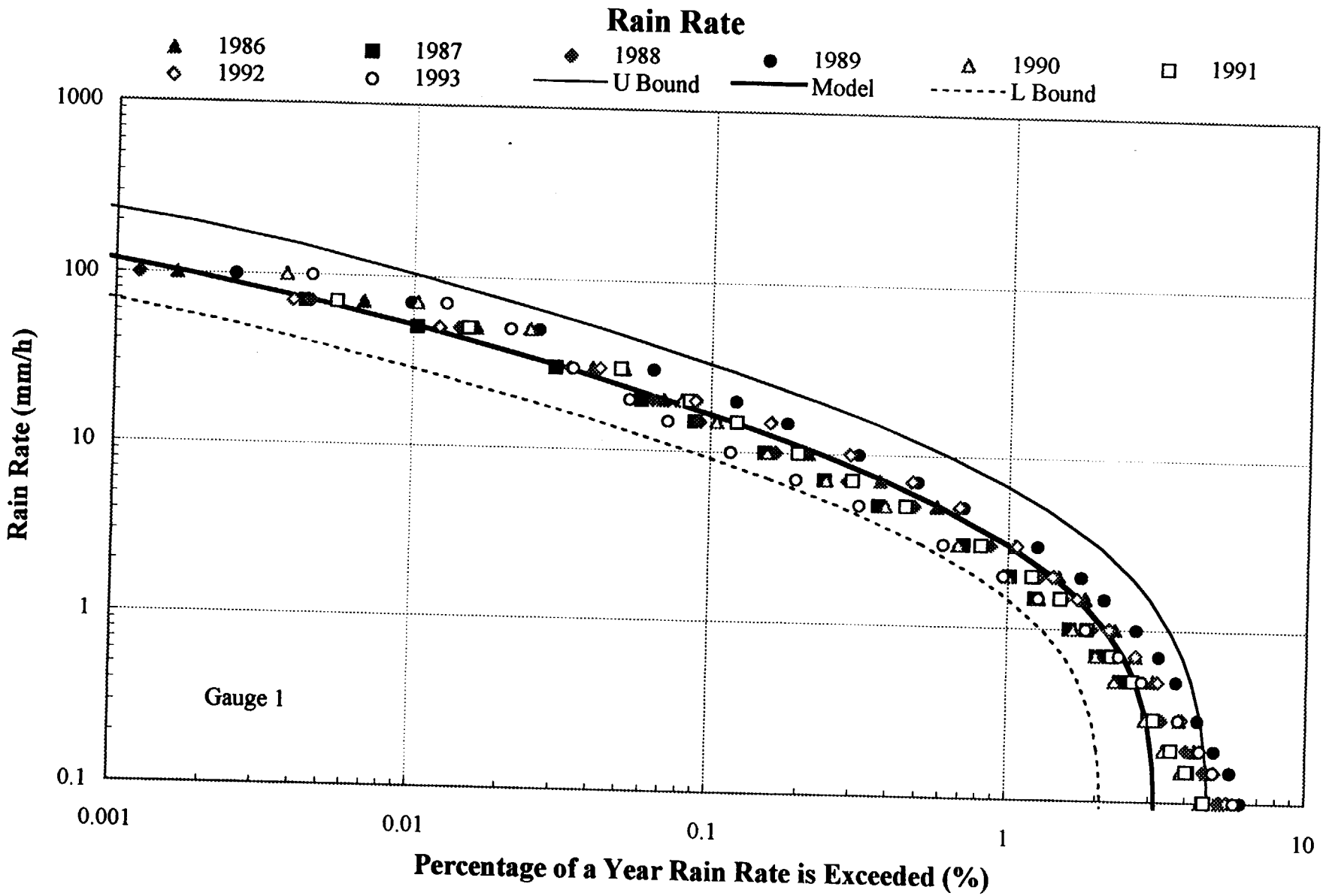



Rain Rate
74_10
76_07
77_08
78_08
76_06
77_06
78_06
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
Solid Markers - Clarksburg, MD
Open Markers - Greenbelt, MD
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)


Rain Rate
1988
1989
1990
1991
1992
1993
1994
1995
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)


Rain Rate
1981
77 06
78 06
1962
1962
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)
1981: Cambridge, MA
'77 & '78: Waltham, MA
1962: W. Concord, MA
Solid Markers 1 min. average
Open Markers 5 min. average

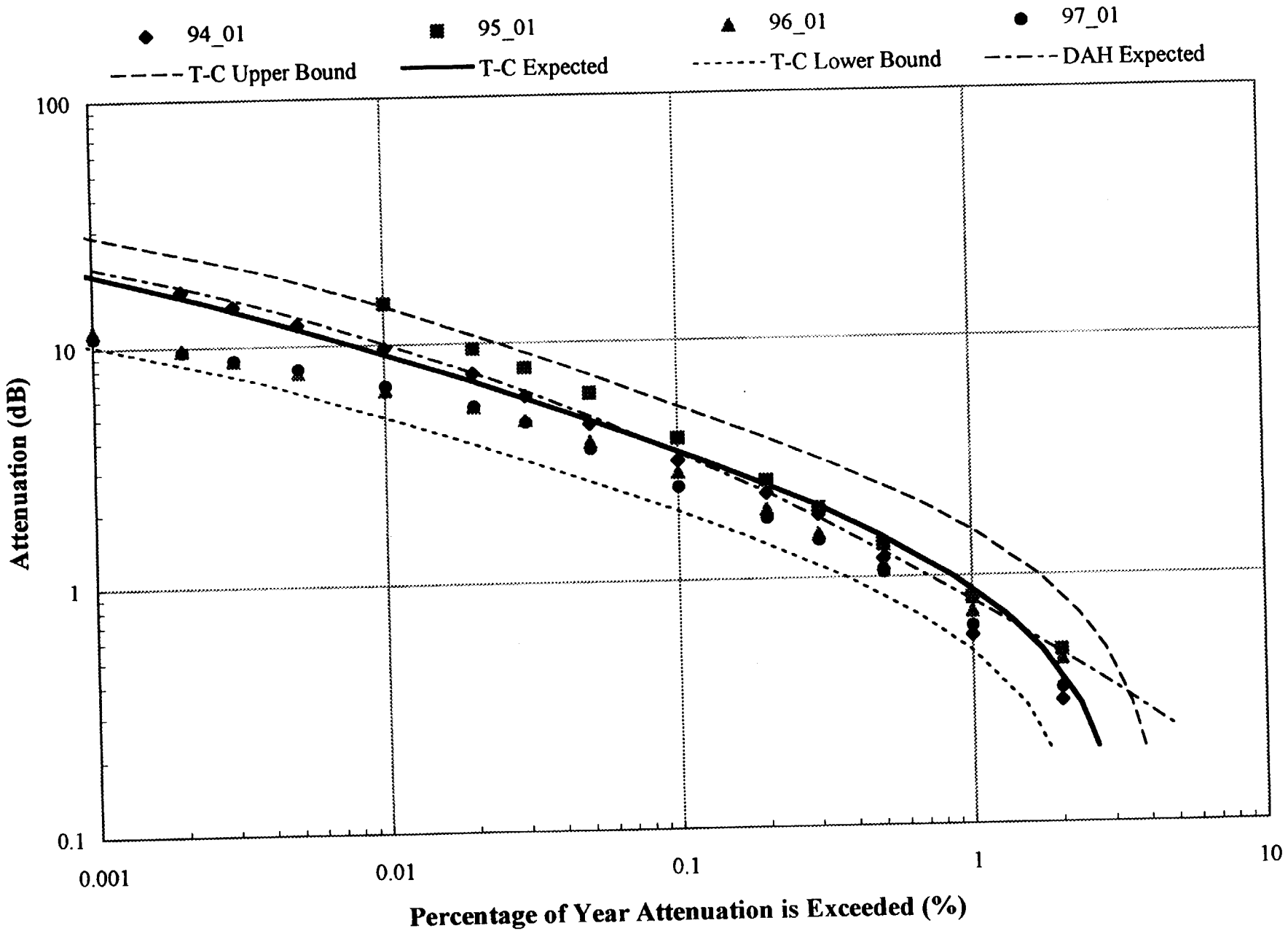

Rain Rate
87_01
88_01
89_01
90_01
87_01
88_01
89_01
90_01
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
Solid Markers - Gauge 5
Open Markers - Gauge 7
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)


Rain Rate
1986
1987
1988
1989
1990
1991
1992
1993
U Bound
Model
L Bound
1000
100
10
1
0.1
Rain Rate (mm/h)
Gauge 1
0.001
0.01
0.1
1
10
Percentage of a Year Rain Rate is Exceeded (%)

20.2 GHz, Alaska

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

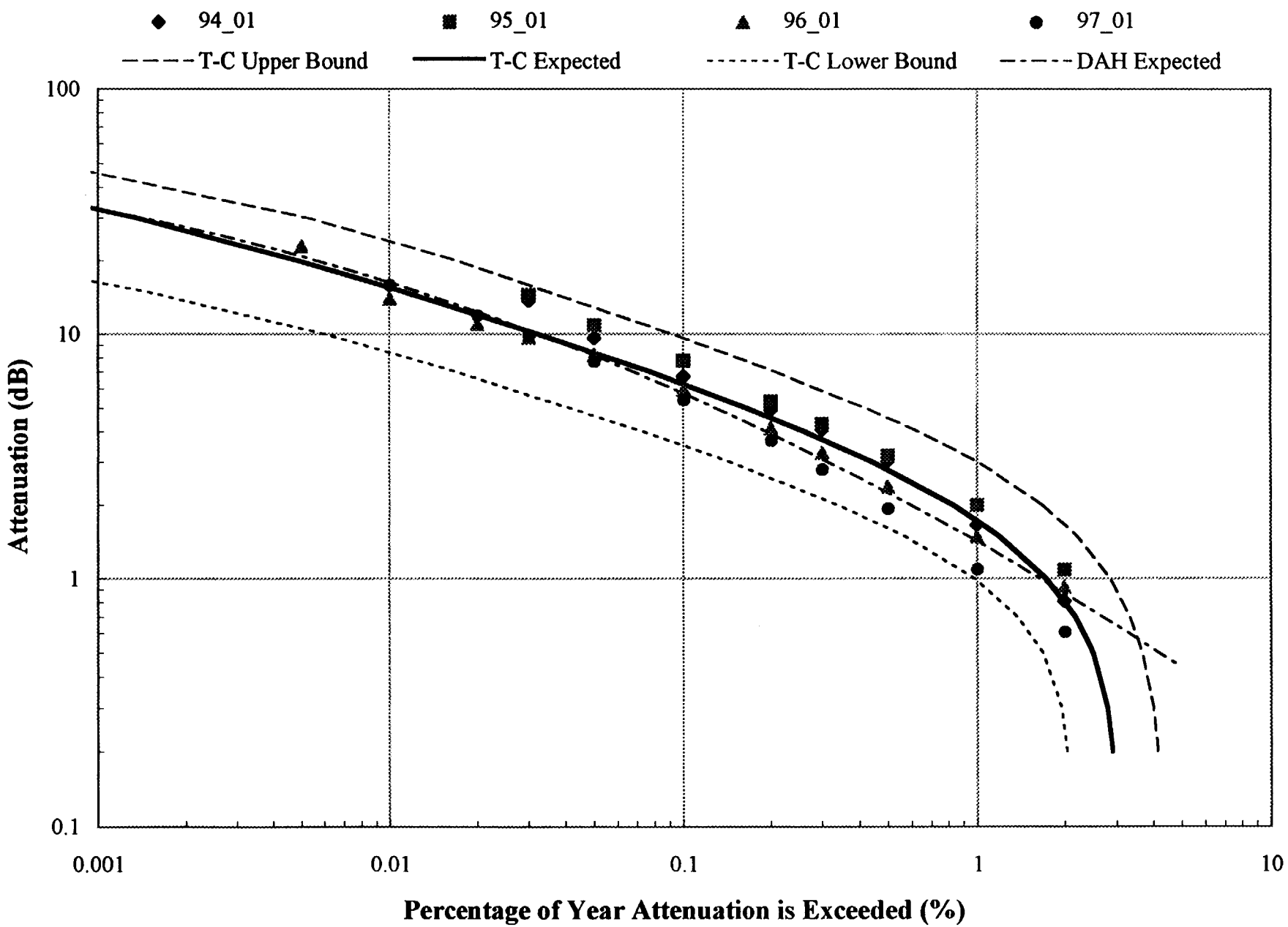
ACTS Propagation Experiment

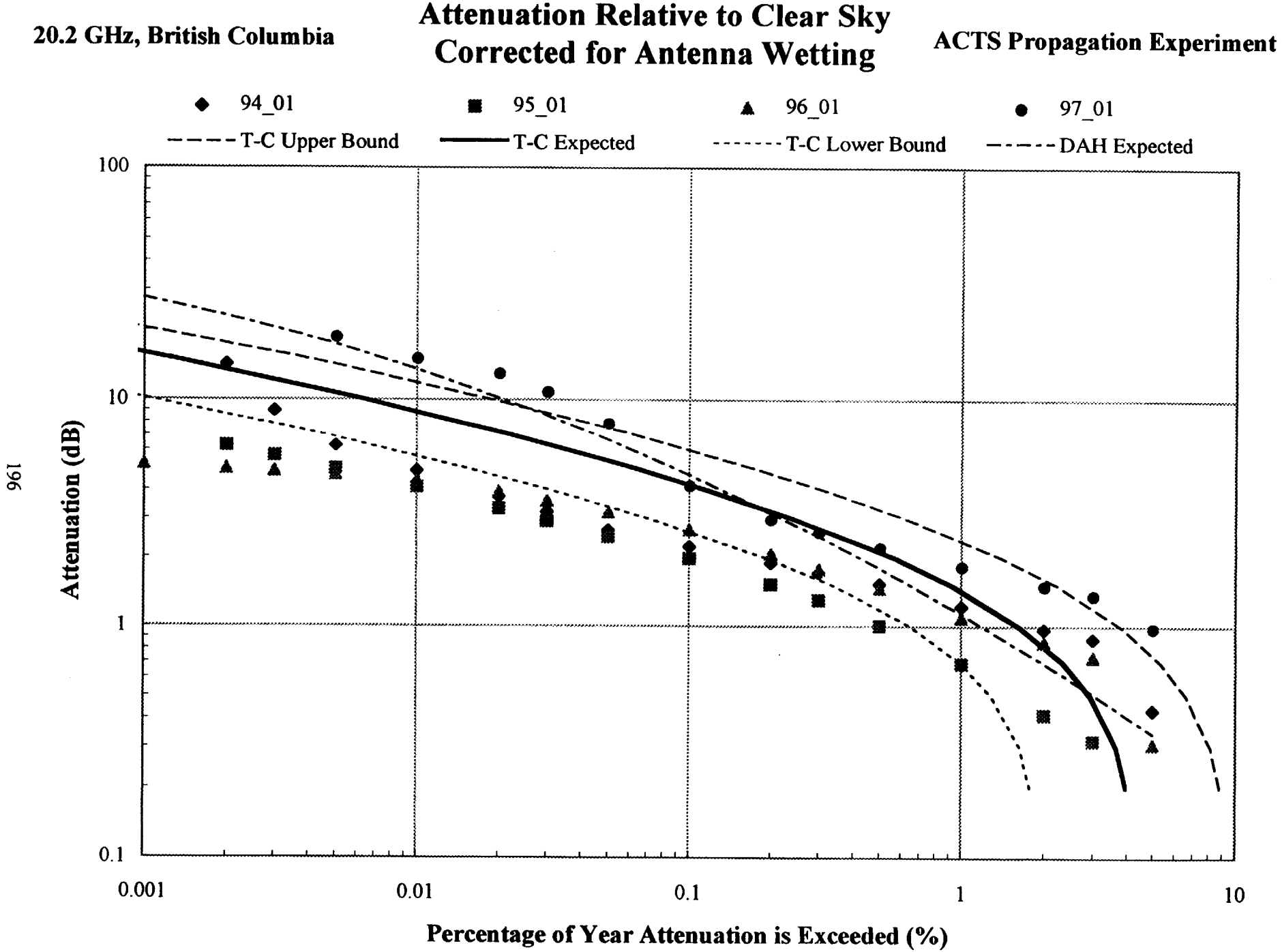


27.5 GHz, Alaska

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

ACTS Propagation Experiment

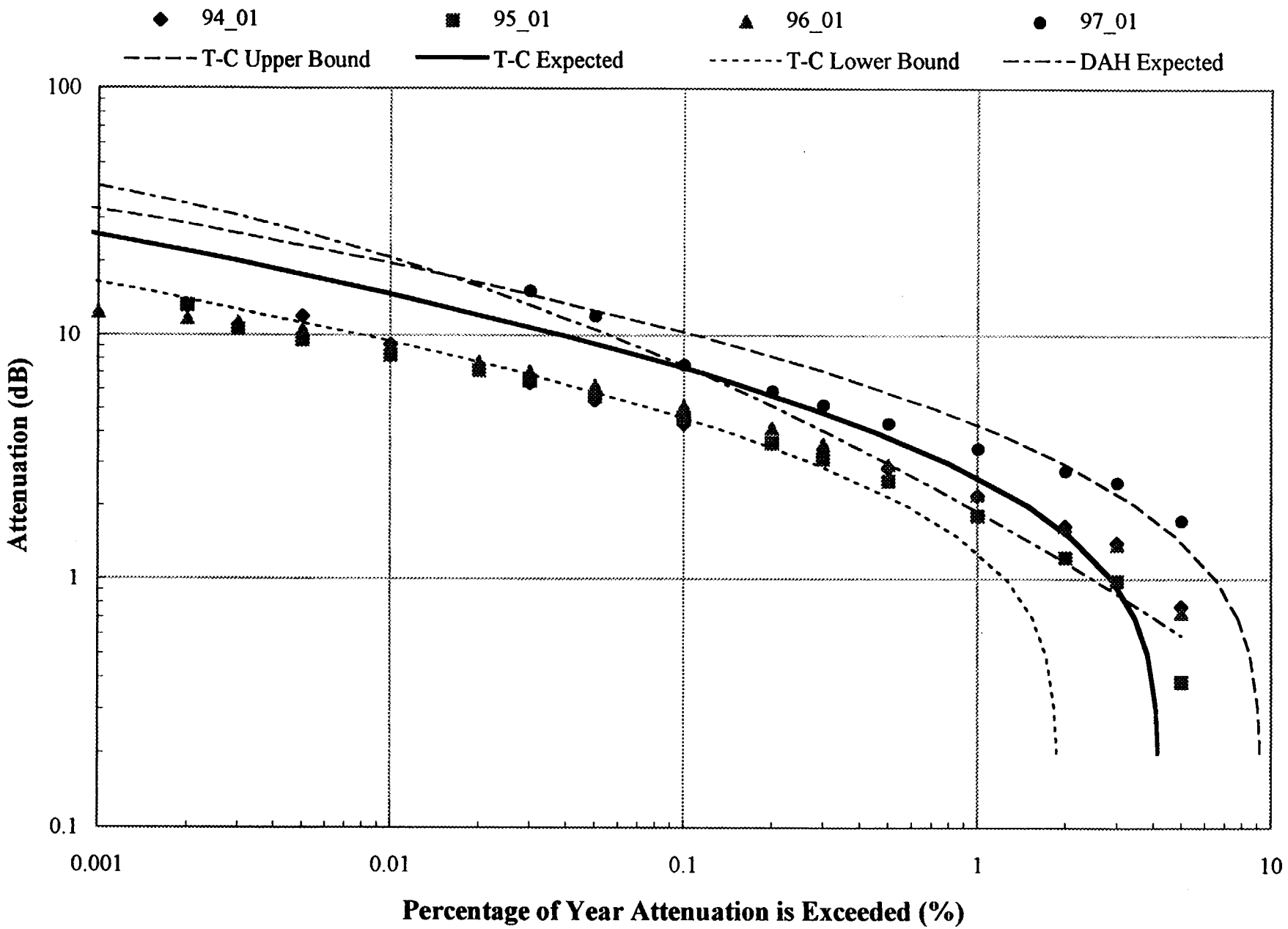



20.2 GHz, British Columbia
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting
ACTS Propagation Experiment
94_01
95_01
96_01
97_01
T-C Upper Bound
T-C Expected
T-C Lower Bound
DAH Expected
100
10
1
0.1
Attenuation (dB)
0.001
0.01
0.1
1
10
Percentage of Year Attenuation is Exceeded (%)

27.5 GHz, British Columbia

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

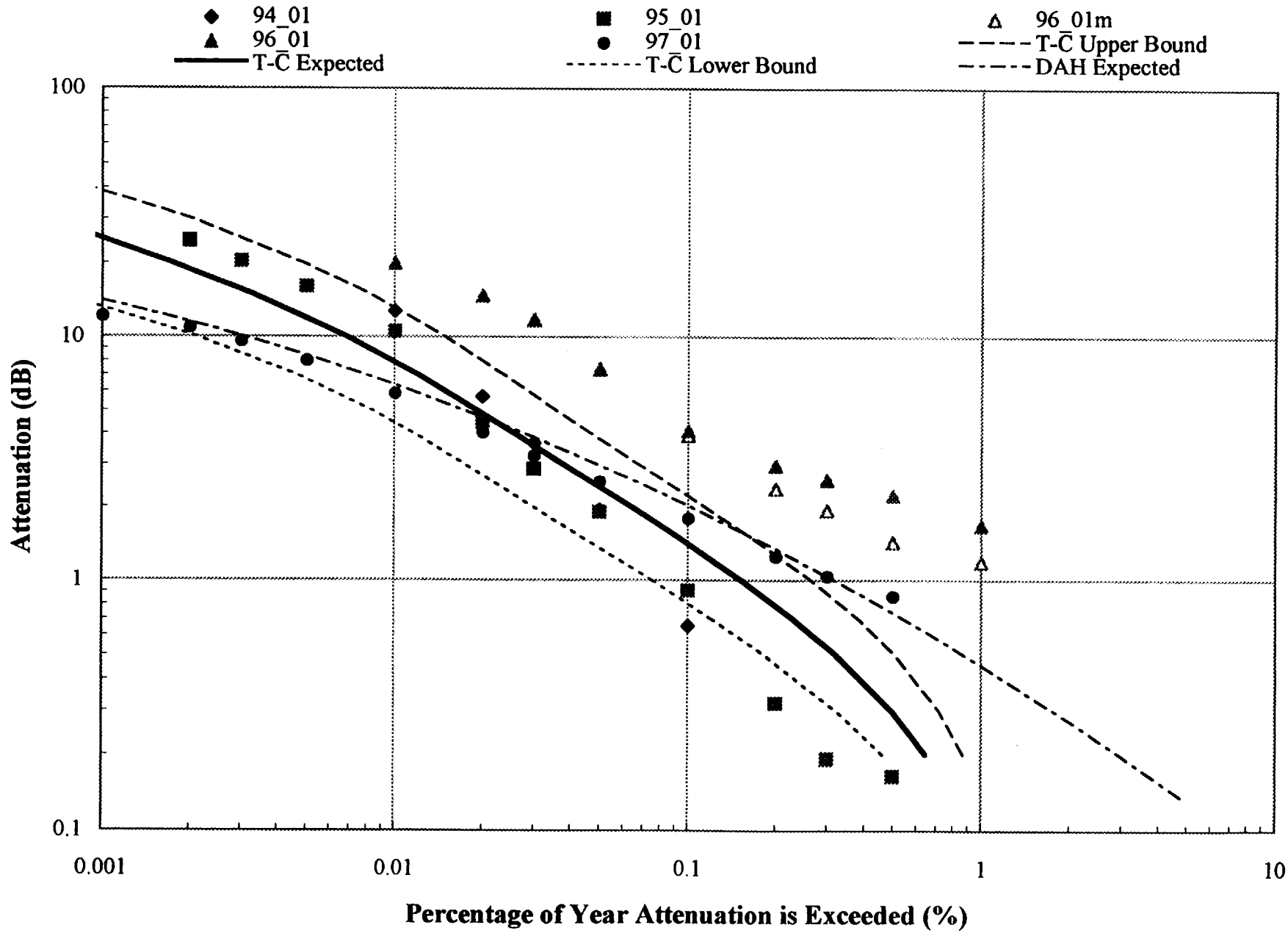
ACTS Propagation Experiment



20.2 GHz, Colorado

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

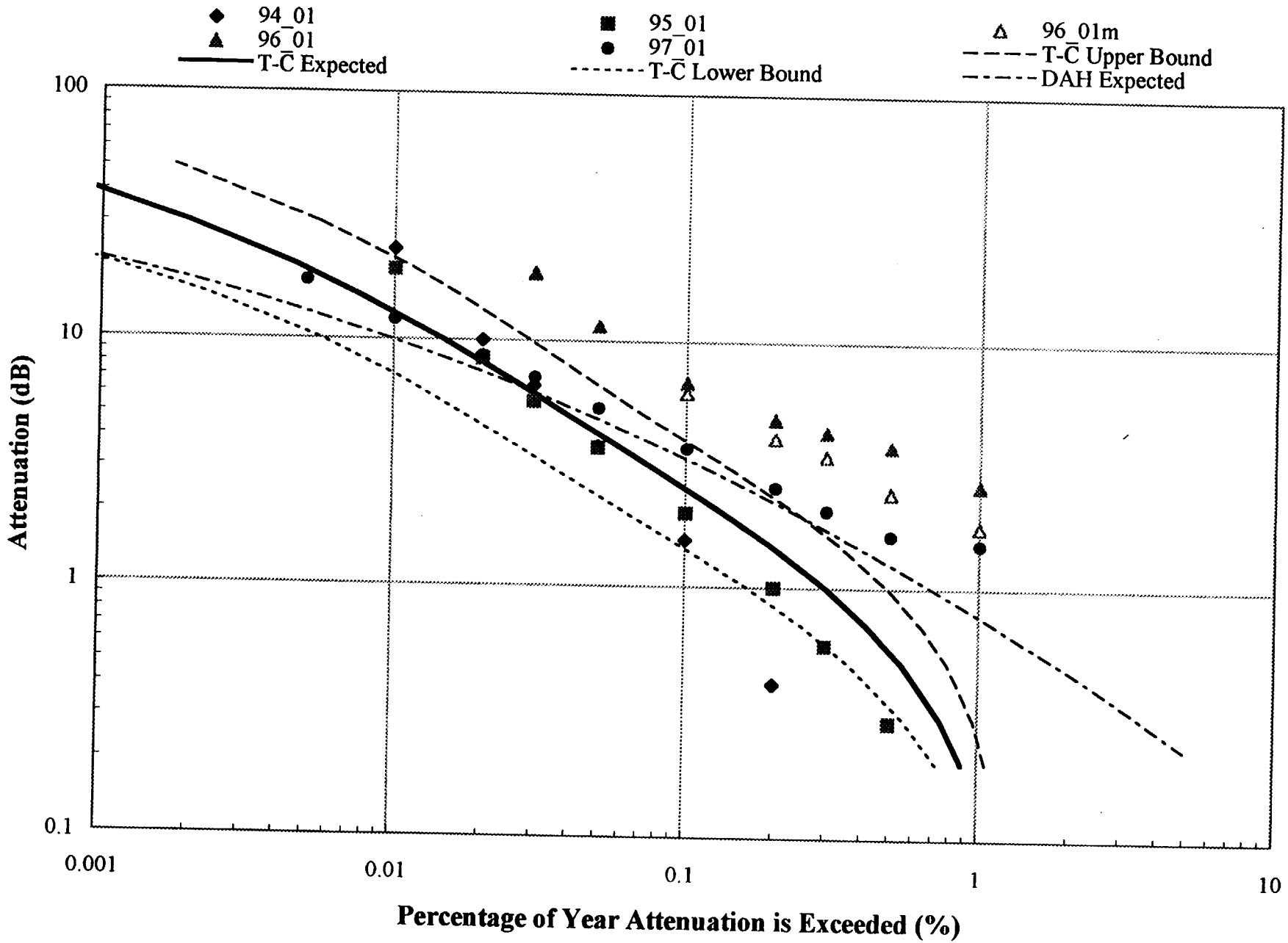
ACTS Propagation Experiment

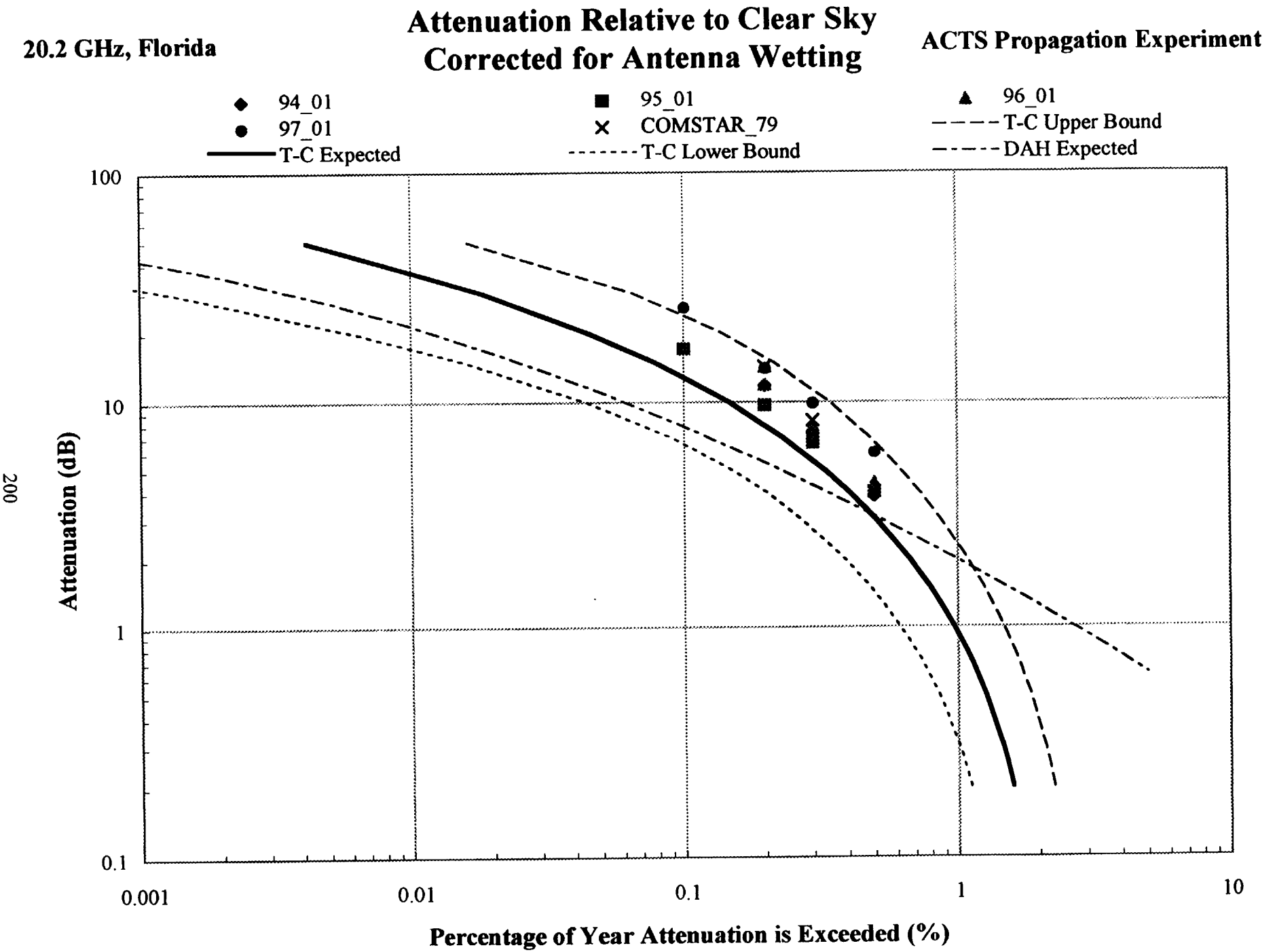


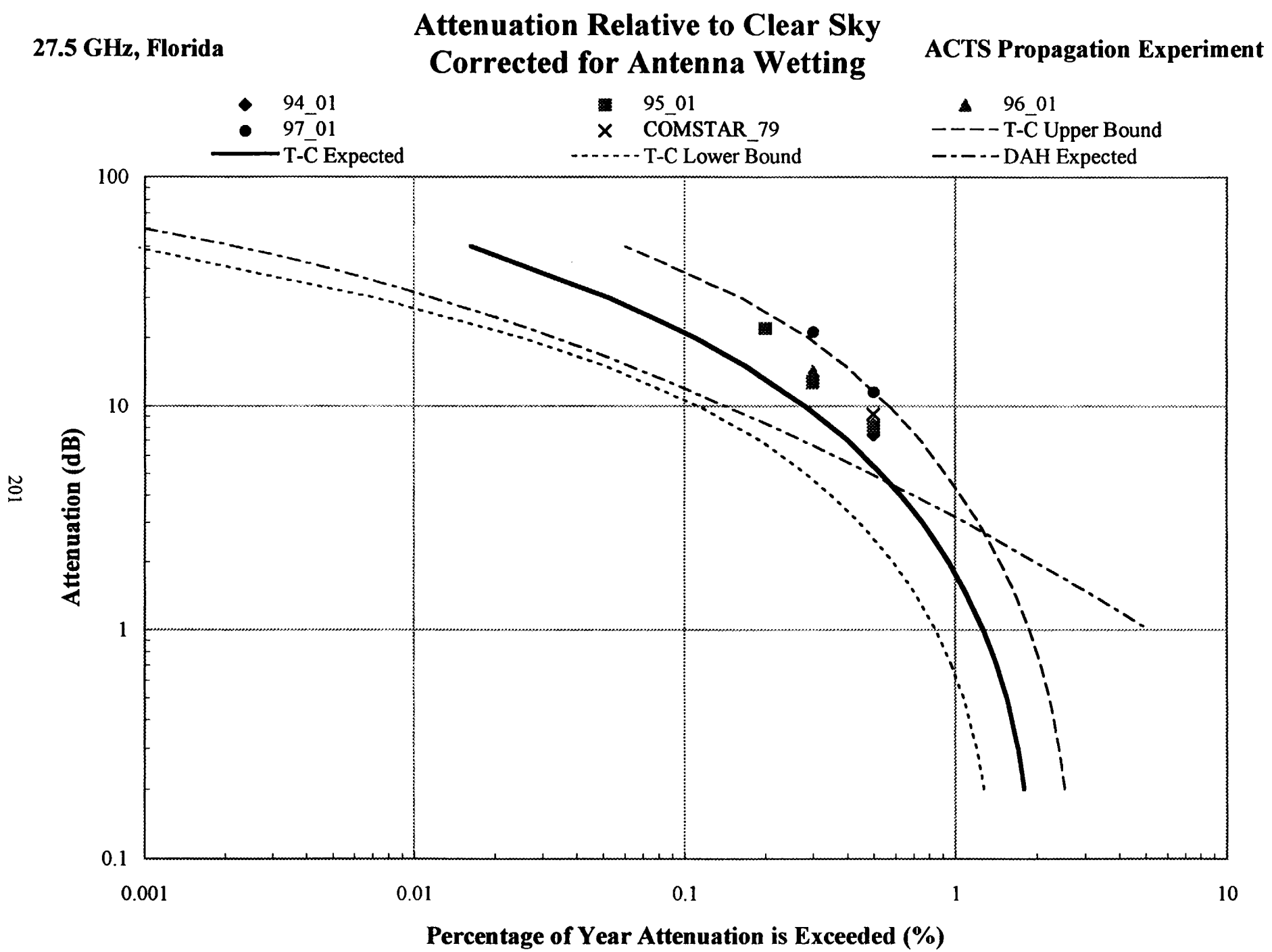
27.5 GHz, Colorado

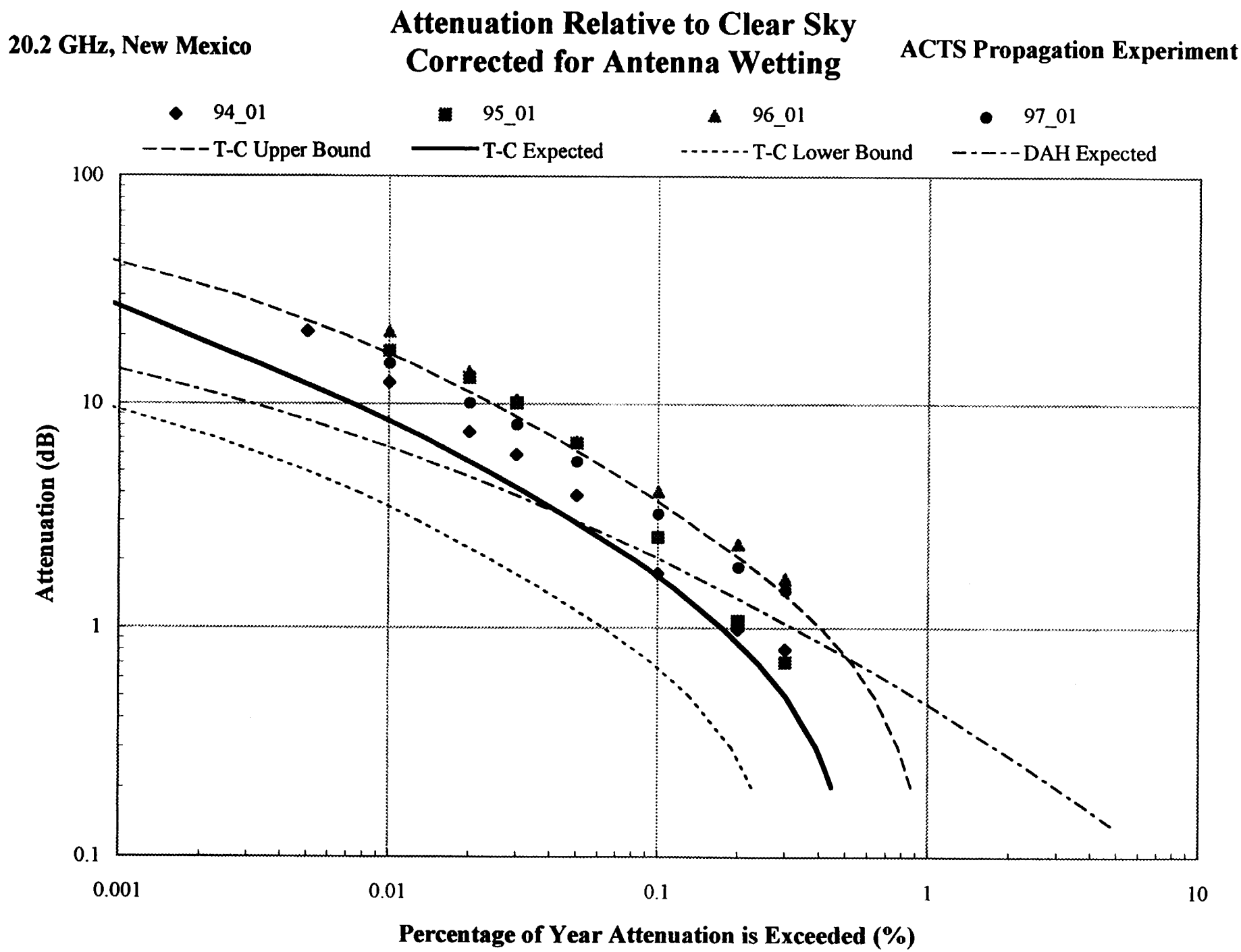
Attenuation Relative to Clear Sky Corrected for Antenna Wetting

ACTS Propagation Experiment




20.2 GHz, Florida
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting
ACTS Propagation Experiment
94_01
97_01
T-C Expected
95_01
COMSTAR_79
T-C Lower Bound
96_01
T-C Upper Bound
DAH Expected
100
10
1
0.1
Attenuation (dB)
0.001
0.01
0.1
1
10
Percentage of Year Attenuation is Exceeded (%)

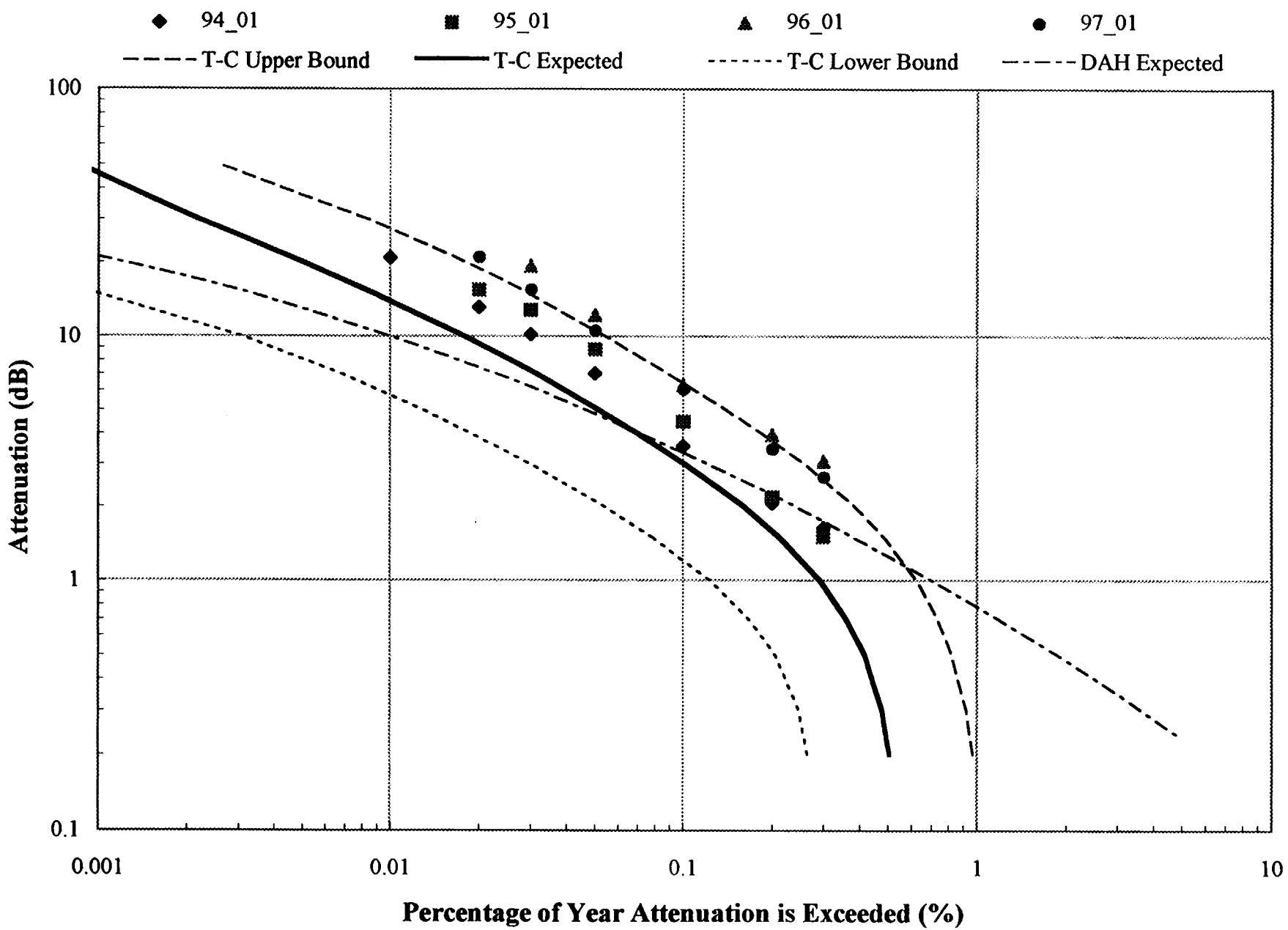

27.5 GHz, Florida
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting
ACTS Propagation Experiment
94_01
95_01
96_01
97_01
COMSTAR_79
T-C Upper Bound
T-C Expected
T-C Lower Bound
DAH Expected
100
10
1
0.1
Attenuation (dB)
0.001
0.01
0.1
1
10
Percentage of Year Attenuation is Exceeded (%)


20.2 GHz, New Mexico
Attenuation Relative to Clear Sky
Corrected for Antenna Wetting
ACTS Propagation Experiment
94_01
95_01
96_01
97_01
T-C Upper Bound
T-C Expected
T-C Lower Bound
DAH Expected
100
10
1
0.1
Attenuation (dB)
0.001
0.01
0.1
1
10
Percentage of Year Attenuation is Exceeded (%)

27.5 GHz, New Mexico

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

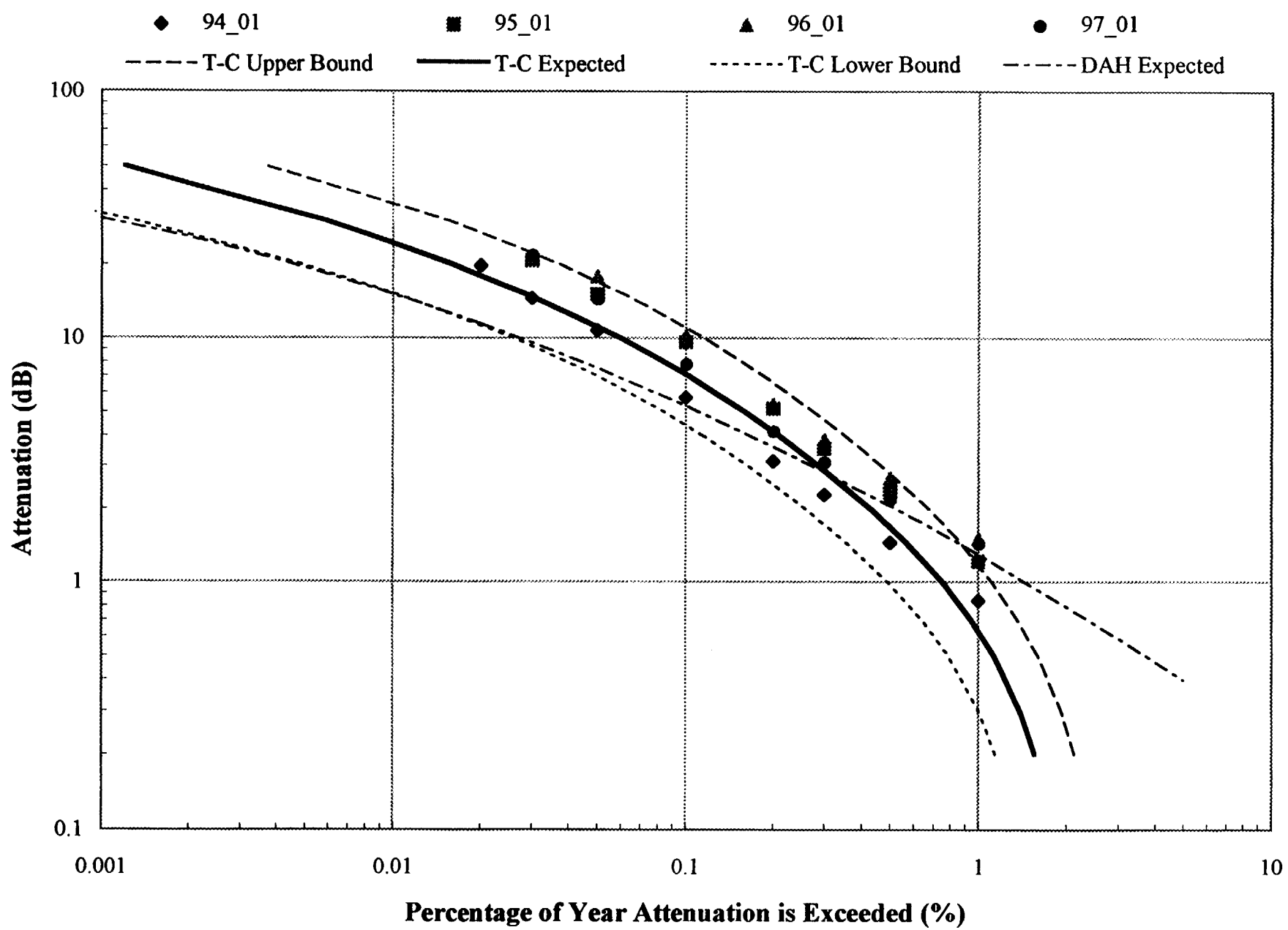
ACTS Propagation Experiment



20.2 GHz, Oklahoma

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

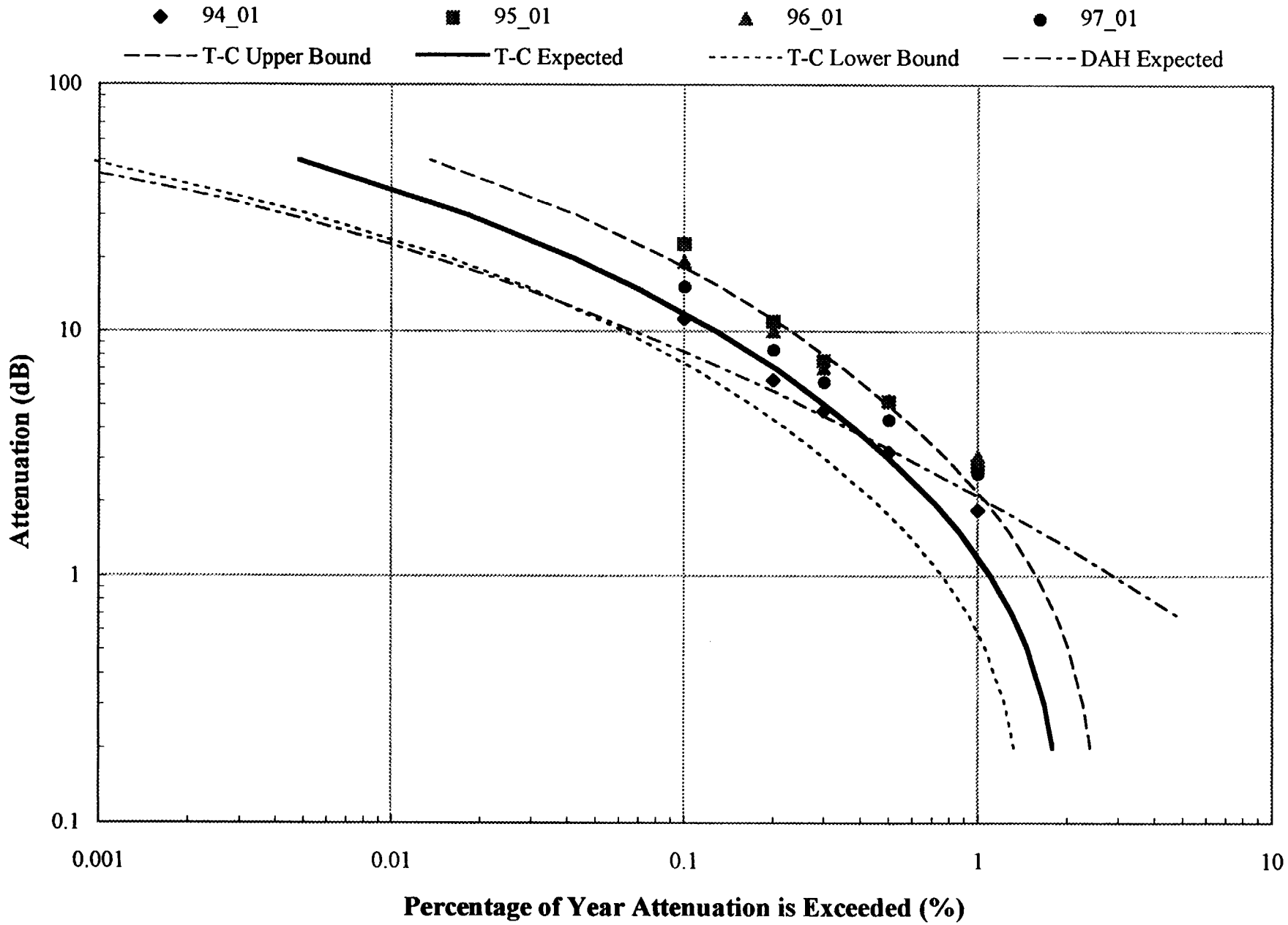
ACTS Propagation Experiment



27.5 GHz, Oklahoma

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

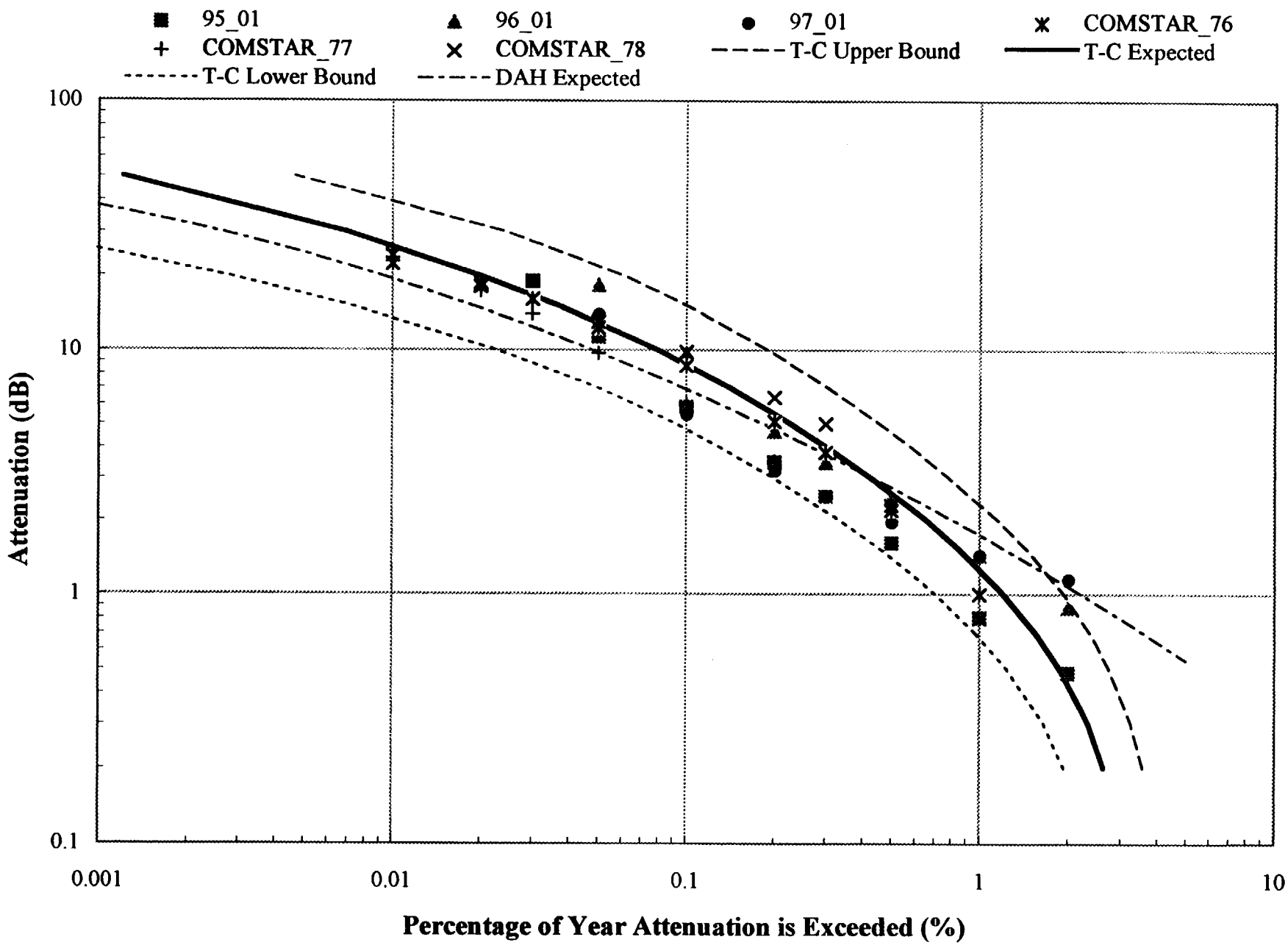
ACTS Propagation Experiment



20.2 GHz, Virginia

Attenuation Relative to Clear Sky Corrected for Antenna Wetting

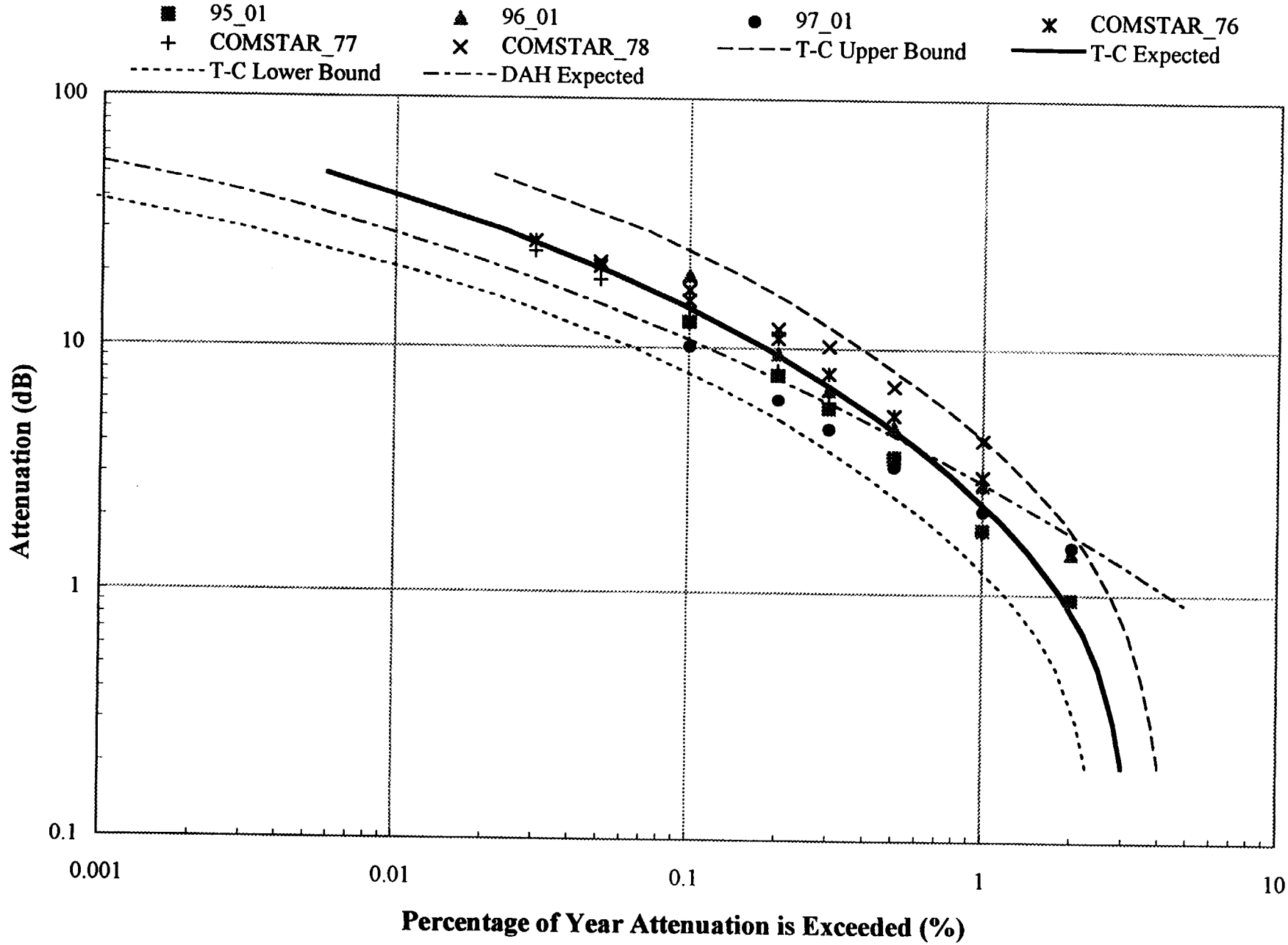
ACTS Propagation Experiment



27.5 GHz, Virginia

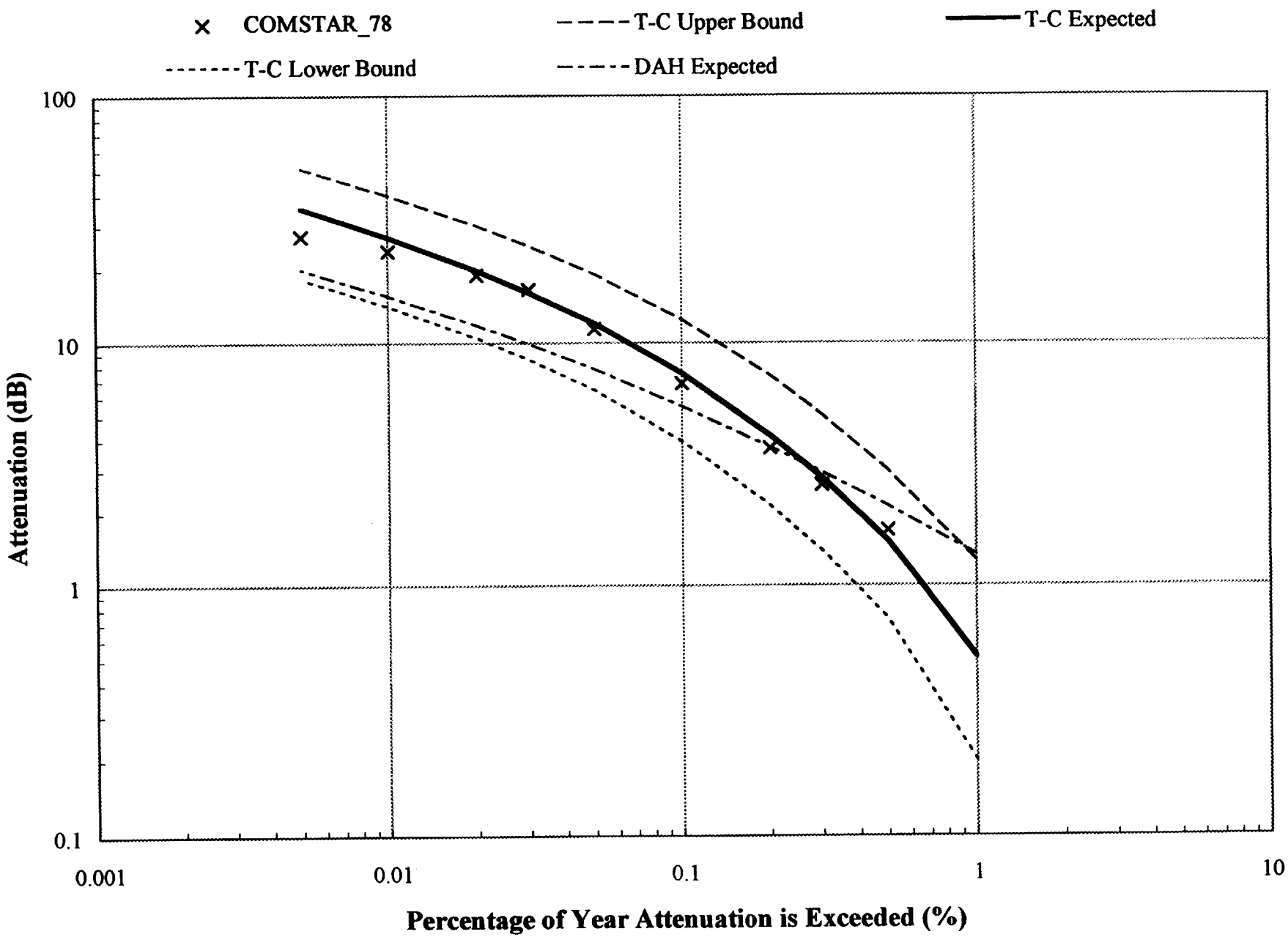
Attenuation Relative to Clear Sky Corrected for Antenna Wetting

ACTS Propagation Experiment



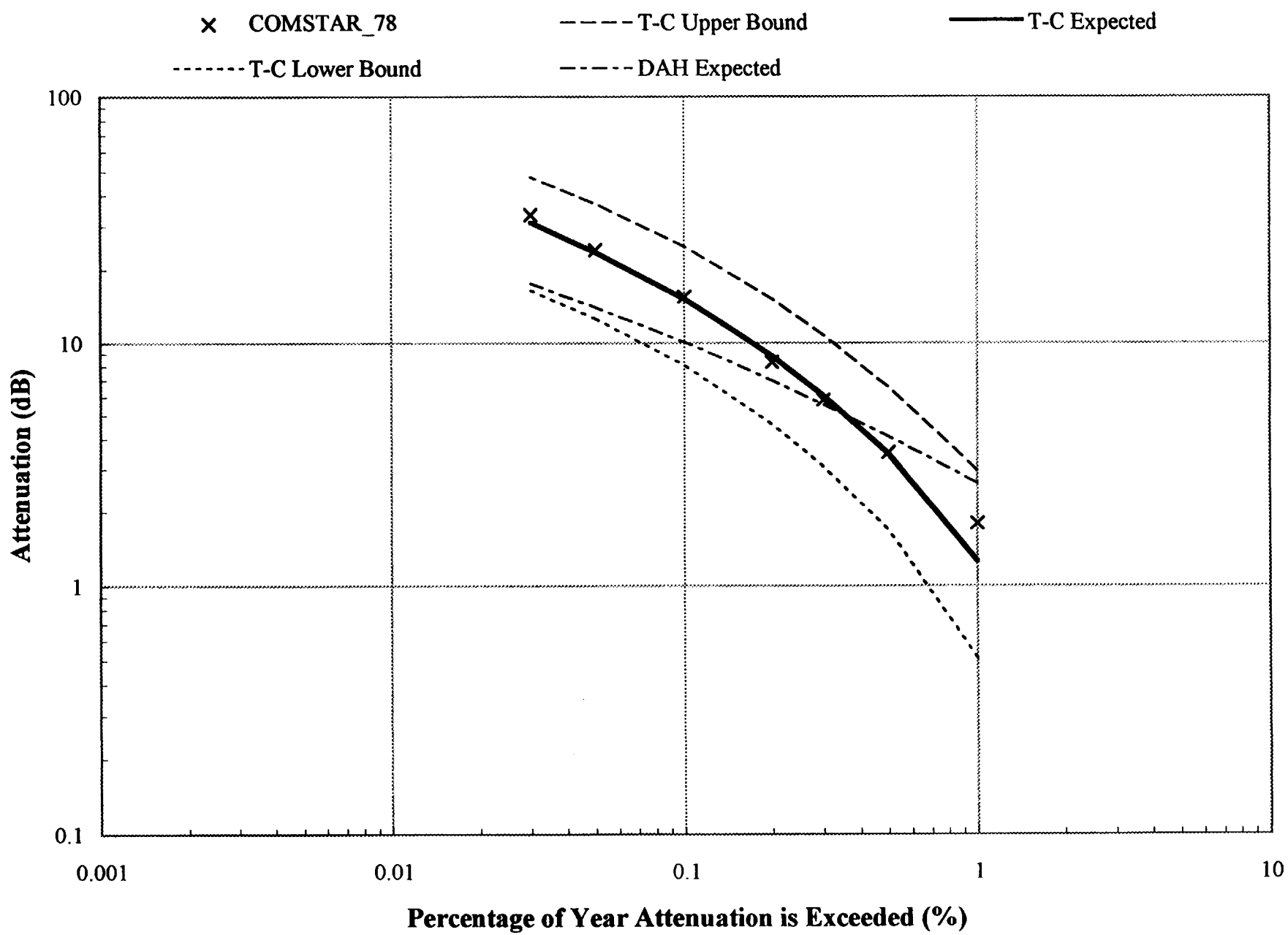
Attenuation Relative to Clear Sky

19.0 GHz, Austin, TX



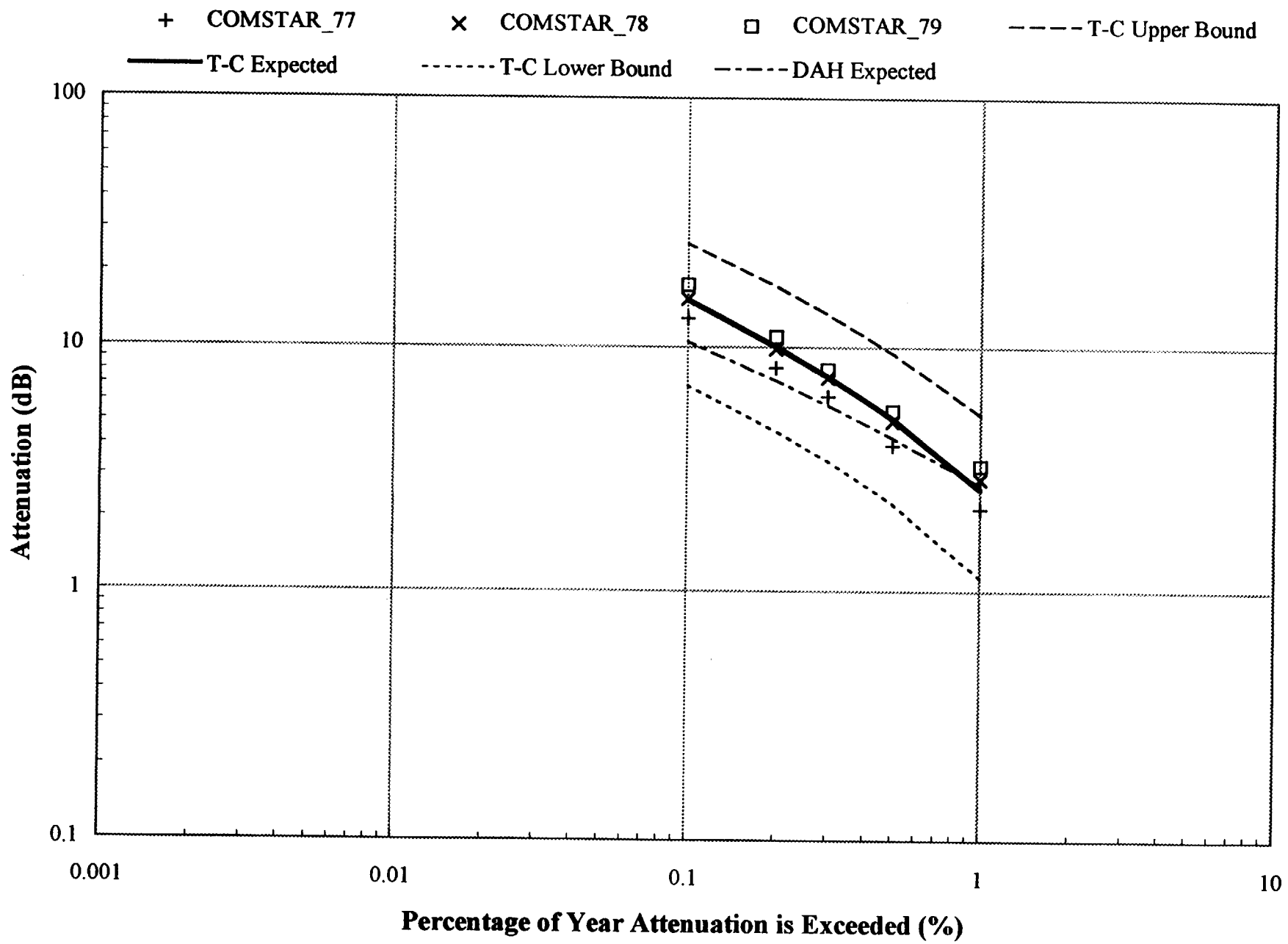
Attenuation Relative to Clear Sky

28.5 GHz, Austin, TX



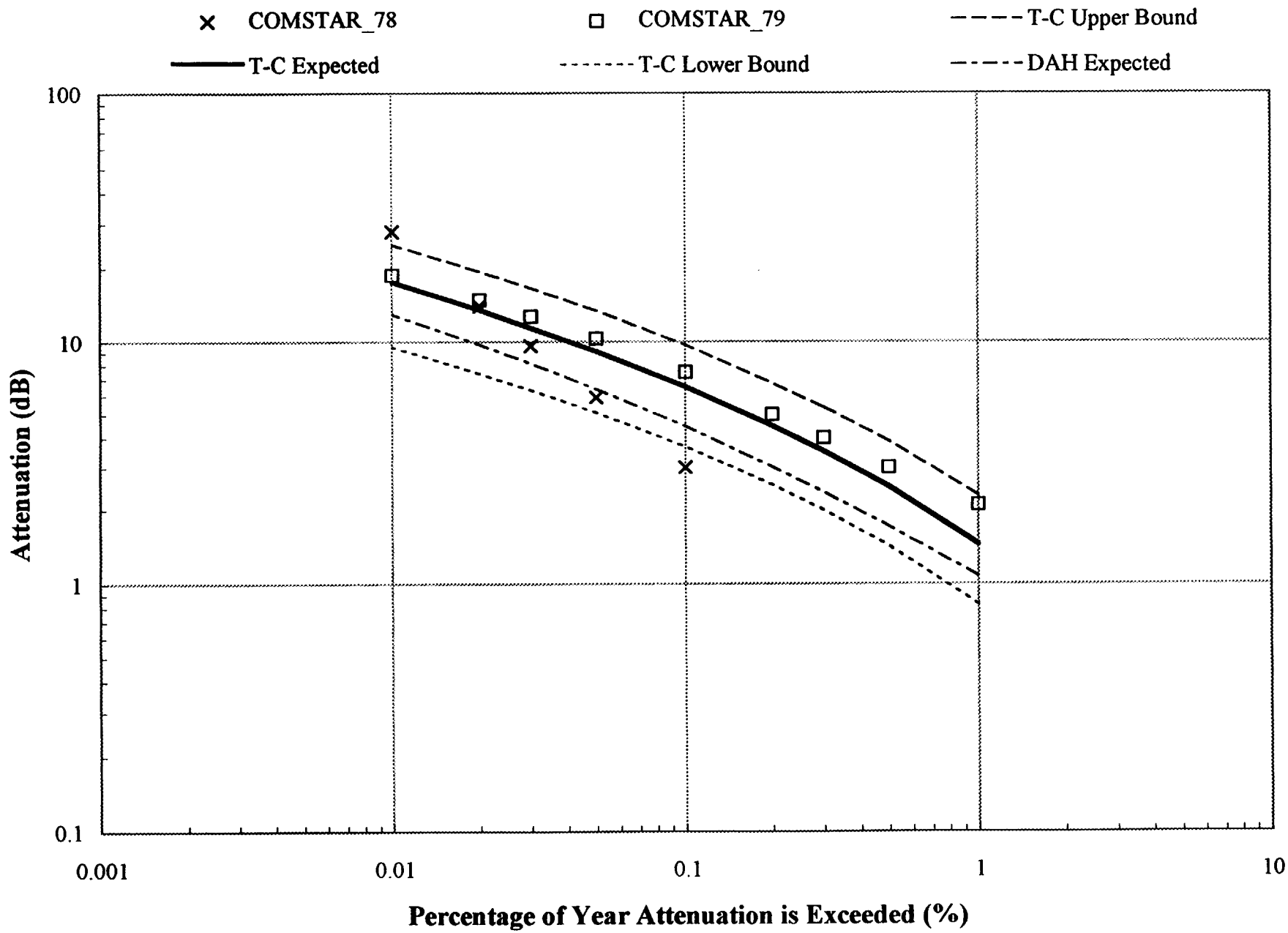
28.5 GHz, Wallops Island

Attenuation Relative to Clear Sky



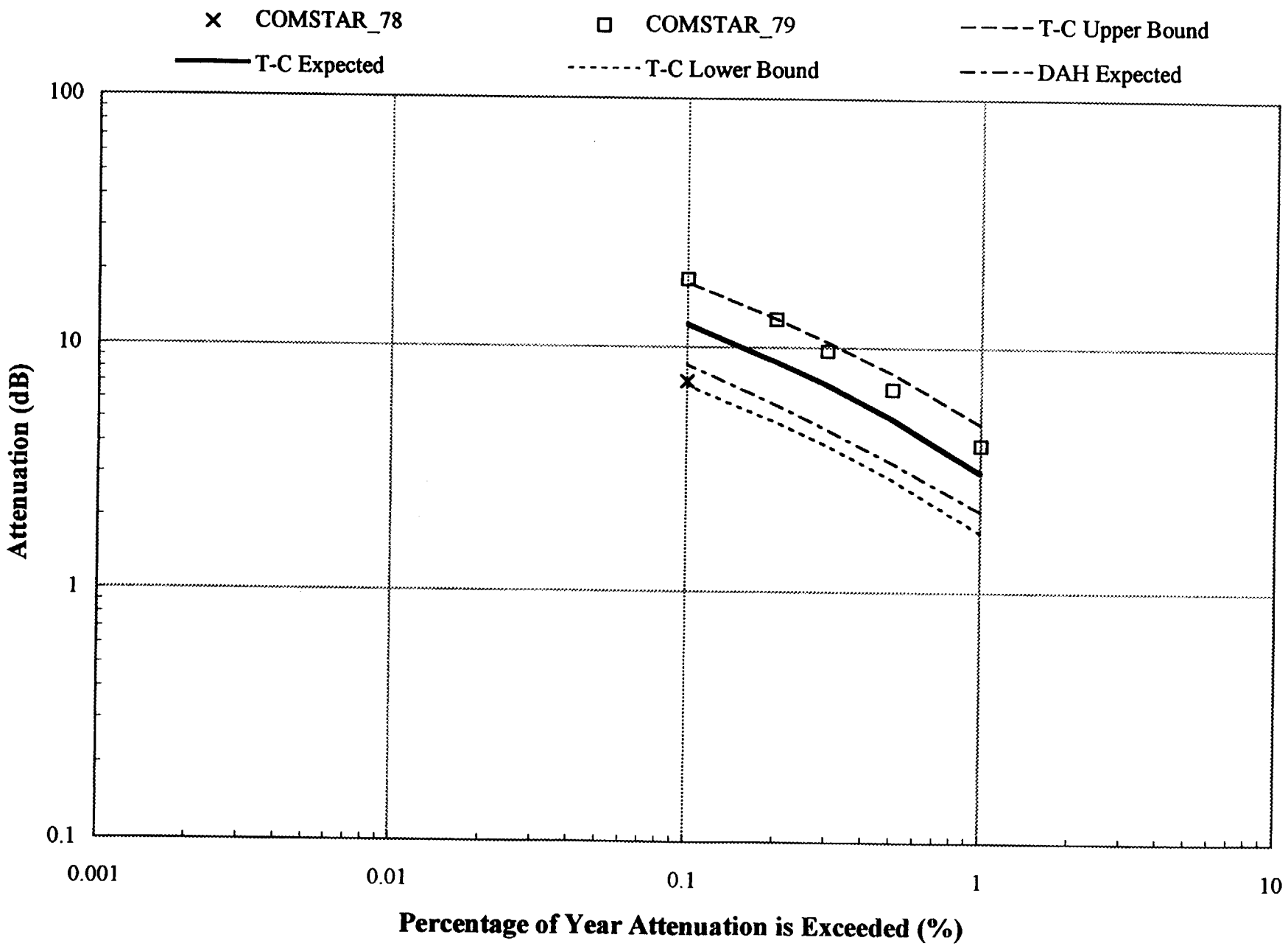
Attenuation Relative to Clear Sky

19.0 GHz, Waltham, MA



28.6 GHz, Waltham, MA

Attenuation Relative to Clear Sky



ACTS Propagation System Status

and

ACTS Propagation Data Base

David B. Westenhaver

Westenhaver Wizard Works, Inc.

746 Lioness Ct SW

Stone Mountain, GA 30087-2855

770-925-1091, wwwinc@crl.com

Presented at ACTS Propagation Studies Workshop XI

Oklahoma City , OK

October 22, 1998

Engineering Support and Systems Upgrades Status

Software Status / Deficiencies and Known Problems

DRX software status:

Current version 17 of 4/25/96.
Need to open beacon acquisition constraints.

DACS software status:

Current version 10 of 4/01/96.
Need to add force beacon reacquisition.
Need to prevent repeating radiometer setups.

TSR software status:

Current version 14 of 6/18/98.
Some Traps added for DOS Critical-Errors.
Works with Zip Drive except when operator error.
Complete Drive:\Path Information added.
Data missing from RV0; May be fixed.
Changed to keep 61 days of *.rv0 data on disc.
High Data Rate files are not automatically removed.
Works with new GPS receivers for Timing.

ActsView software status:

Current version 4.5 of 8/6/97.

Actspp PreProcessing software status:

Current version 7.4 of 8/19/98.

ACTS Data Center RAW Data Files as of 10-15-1998

Yr	Month	AK	BC	CO	FL	MD	NM	OK
93	Dec	31	31	30	28	..	29	31
94	Jan	31	31	31	31	..	31	31
94	Feb	28	28	28	28	..	26	28
94	Mar	31	31	31	29	17	31	31
94	Apr	30	30	30	30	30	30	30
94	May	31	31	25	30	31	31	31
94	Jun	30	30	30	30	30	30	30
94	Jul	31	31	31	31	31	31	31
94	Aug	31	31	31	31	31	31	31
94	Sep	30	30	29	30	30	30	30
94	Oct	31	31	29	31	31	31	31
94	Nov	27	30	30	30	30	30	30
94	Dec	31	31	31	28	22	31	31
95	Jan	31	31	31	31	19	31	31
95	Feb	28	28	28	28	28	28	28
95	Mar	31	31	31	31	31	31	31
95	Apr	30	30	30	30	28	30	30
95	May	31	31	31	31	31	31	31
95	Jun	30	30	30	30	30	30	30
95	Jul	31	31	31	31	31	31	31
95	Aug	31	30	31	31	31	31	31
95	Sep	30	30	30	30	30	30	30
95	Oct	31	31	31	31	31	31	31
95	Nov	30	30	30	30	30	30	30
95	Dec	31	31	31	31	31	31	31
96	Jan	31	31	31	31	31	31	31
96	Feb	29	29	27	29	29	27	29
96	Mar	31	31	30	31	31	24	31
96	Apr	30	30	30	30	20	30	30
96	May	31	31	31	31	31	31	31
96	Jun	30	30	30	30	30	30	30
96	Jul	31	31	23	31	31	31	31
96	Aug	31	31	31	31	31	31	31
96	Sep	30	30	29	28	30	30	30
96	Oct	31	31	28	31	30	31	31
96	Nov	30	30	30	30	23	30	30
96	Dec	31	31	31	31	31	26	31
97	Jan	31	31	31	31	31	29	31
97	Feb	28	28	28	28	28	28	28
97	Mar	31	31	31	31	31	31	31
97	Apr	30	30	30	30	30	27	30
97	May	31	30	31	31	31	31	31
97	Jun	30	30	24	30	30	30	30
97	Jul	30	31	31	31	31	24	31
97	Aug	31	31	31	31	31	31	31
97	Sep	30	30	21	30	30	30	30
97	Oct	31	31	30	13	29	31	31
97	Nov	30	30	30	17	30	30	30
97	Dec	31	31	31	31	31	31	31
98	Jan	31	31	31	31	31	31	31
98	Feb	28	28	28	28	28	28	28
98	Mar	31	31	27	31	31	31	31
98	Apr	30	30	26	30	30	30	30
98	May	31	31	21	31	25	30	31
98	Jun	30	30	30	30	16	25	29
98	Jul	31	31	31	31	31	31	31
98	Aug	31	31	31	31	..	31	31 Due
98	Sep	..	..	30	30	..	..	30

Total Daily RV0 Files: 11,894
Total Compressed MegaBytes: 4,091

ACTS Data Center Processed Data Files as of 10-15-1998

Yr	Month	AK	BC	CO	FL	MD	NM	OK
93	Dec	31	31	30	28	..	29	31
94	Jan	31	31	31	31	..	31	31
94	Feb	28	28	28	28	..	26	28
94	Mar	31	31	31	29	17	31	31
94	Apr	30	30	30	30	30	30	30
94	May	31	31	25	30	31	31	31
94	Jun	30	30	30	30	30	30	30
94	Jul	31	31	31	31	31	31	31
94	Aug	31	31	31	31	31	31	31
94	Sep	30	30	29	30	30	30	30
94	Oct	31	31	29	31	31	31	31
94	Nov	27	30	30	30	30	30	30
94	Dec	31	31	31	28	22	31	31
95	Jan	31	31	31	31	19	31	31
95	Feb	28	28	28	28	28	28	28
95	Mar	31	31	31	31	31	31	31
95	Apr	30	30	30	30	28	30	30
95	May	31	31	31	31	31	31	31
95	Jun	30	30	30	30	30	30	30
95	Jul	31	31	31	31	31	31	31
95	Aug	31	30	31	31	31	31	31
95	Sep	30	30	30	30	30	30	30
95	Oct	31	31	31	31	31	31	31
95	Nov	30	30	30	30	30	30	30
95	Dec	31	31	31	31	31	31	31
96	Jan	31	31	31	31	31	31	31
96	Feb	29	29	27	29	29	27	29
96	Mar	31	31	30	31	31	24	31
96	Apr	30	30	30	30	20	30	30
96	May	31	31	31	31	31	31	31
96	Jun	30	30	30	30	30	30	30
96	Jul	31	31	23	31	31	31	31
96	Aug	31	31	31	31	31	31	31
96	Sep	30	30	29	28	30	30	30
96	Oct	31	31	28	31	30	31	31
96	Nov	30	30	30	30	23	30	30
96	Dec	31	31	31	31	31	26	31
97	Jan	31	31	31	31	31	29	31
97	Feb	28	28	28	28	28	28	28
97	Mar	31	31	31	31	31	31	31
97	Apr	30	30	30	30	30	27	30
97	May	31	30	31	31	31	31	31
97	Jun	30	30	24	30	30	30	30
97	Jul	30	31	31	31	31	24	31
97	Aug	31	31	31	31	31	31	31
97	Sep	30	30	21	30	30	30	30
97	Oct	31	31	30	13	29	31	31
97	Nov	30	30	30	17	30	30	30
97	Dec	31	31	31	31	31	31	31
98	Jan	31	31	31	31	31	31	31
98	Feb	28	28	28	28	28	28	28
98	Mar	31	31	28	31	31	31	31
98	Apr	30	..	26	30	30	30	30 Due
98	May	31	..	21	31	25	30	31 Due
98	Jun	30	..	..	30	..	25	29 Due
98	Jul	31	..	..	31	..	31	.. Due
98	Aug	..	..	..	31	..	..	..

Total Daily PV2 Files: 11,388
Total Compressed MegaBytes: 3,086

ACTS Propagation Data Base Procedures Review

- The detailed Data Base Procedures described in June 98 have worked very well.
- The logs indicate over 60 archive input sessions - over 10,000 days of data since June 98.
- The primary archives are on 2 each 6.4 GB disk (D:\ for processed data and E:\ for raw data).
- All processed and new raw data are copied to an "Image" 8.5GB disk on another PC.
- The new processed and raw files are transferred to a CD when we have >550 MB.
- The Archived RAW data CDs for 9312 - 9808 are in the vault.
- The Archived Processed CDs for 9312 - 9712 are in the vault.
- Several sites have requested CDs of the "current as of this date" archived raw data.
- Are new "current as of this date" archived raw data CDs needed? Send me an email request.

Archived data on CDs is the primary data source for the Experimenters.

4 Year ACTS Propagation Data Quality Checking is still in Progress.

- The current checking programs are Rd_log6 and Rd_edf3.
- The new updates have been improved to detect more "questionable data" - data that needs another review.
- The yymmxx.log files are scanned using the Rd_log program.
- The yymmxx.edf files are scanned using the Rd_edf program.
- The most common "questionable data" are a result of:
  - "Clear Sky Delta" is higher than expected.
  - "High Bias Coeff" which is an indication of a higher than expected system gain change or wet snow on the antenna or antenna pointing errors .
  - "Ratio errors" which is an indication that the length of time for the Beacon to Radiometer ratio is higher than expected due to calibration error or water in the wave guide or feed horn.
  - "Stray Sec" which may be an indication that data should be marked "bad" due to a step change in system gain.
- The "questionable data" have been reviewed with the experimenters.
- When water is known to be in the feed horn the calibration should be done daily.
- Many sites have reprocessed all data and it has been entered into the Archives.
- There are still days with "questionable data" in the Archives after the Quality Checking of the PreProcessed data. Further review of these days data is needed to resolve these "questions" in our data archives.

ACTS Propagation Data CD-ROM Distribution

- The 4 year Peer Review Copies were distributed Sept. 25 to the Experimenters.
- Request for comments from the ACTS Experimenters of the Peer Review data on the CDs.
- By site: AK, BC, CO, FL, MD, NM, OK
- We have more copies for distribution. The Data Request form must be filled out, signed and reviewed before distribution.
- Please read the Readme.txt file first.

SESSION 3. SPECIAL TOPICS

Chair: J. Goldhirsh

(JHU/APL)

Rain Attenuation Modeling

Asoka Dissanayake

23 October 1998

Background

* Rain attenuation is a key limiting factor in the introduction of higher frequency bands into satellite and terrestrial microwave systems.

* Limited knowledge of the rain process makes it difficult to come up with accurate predictions of rain attenuation .

* An average prediction accuracy better than 25% appears difficult to achieve; higher accuracies are desirable for communication system design purposes.

DAH Model

* A need for an improved propagation model was identified to facilitate:
  - introduction of higher frequency services into tropical areas
  - reliable attenuation prediction for low elevation angle links
  - design of low availability services.

* This resulted in the development of the DAH model.

DAH Model

* DAH model contains methodologies to predict
  - rain attenuation,
  - cloud attenuation,
  - melting layer attenuation, and
  - low angle fading.

* These are combined with the ITU prediction methods for
  - gaseous absorption and
  - tropospheric scintillations

to predict combined attenuation along satellite paths.

Model Components

* Rain attenuation: empirical approach based on statistical models and available measured path attenuation data.

* Cloud attenuation: makes use of long term observations of cloud cover data with average cloud properties

* Low angle fading: extension to the ITU tropospheric scintillation model based on low-elevation angle measurements on satellite links.

Rain Attenuation Prediction

* Input parameters:
  System related - frequency, polarization, elevation angle
  Rain related - rain rate distribution or rain rate at a given probability, rain height, drop size distribution, temperature, spatial correlation of rain intensity, year to year variability of rainfall.
* Output: attenuation exceeded for a given percentage of time
* Requirements: easy access of input parameters, applicability across a wide range of inputs

Log-normal Model

* Both rain rate and path attenuation can be adequately described in terms of log-normal statistics (three parameter distribution)

$$P(r > R) = P_o/2 \; \mathrm{erfc}[(\ln r - \ln \mu_R)/(\sqrt{2}\,\sigma_R)]$$
$$P(a > A) = P_L/2 \; \mathrm{erfc}[(\ln a - \ln \mu_A)/\sqrt{2}\,\sigma_A)]$$

P_o - probability of rain falling at a point;
P_L - probability of rain falling on the path

* P_L is a function of Po , path length, and rain climate

$$P_L = f(P_o, L, R)$$

Path Averaged Rain Rate

* Path averaged rain rate is a useful concept in developing rain attenuation prediction methods.

* Conversion of point rain rate statistics to path averaged statistics through spatial correlation function: $\rho(L)$.

* $\rho(L)$ can be established using radar or rain gauge network data

* Spatial correlation modeled as a function of distance and rain climate using:

$$\rho(L) = \exp(-\alpha\sqrt{L})$$

$$\alpha = 0.007\, R_{0.01}$$

Simplified Prediction Model

* Log-normal model requires full rain rate distribution including the probability of rain falling at a point.
* To simplify the attenuation prediction, a model centered around the 0.01% rain rate (similar to the ITU model) was devised by introducing:
  - a horizontal path adjustment factor to account for horizontal inhomogeneity of rain and
  - a vertical adjustment factor to account for vertical inhomogeneity
* Both factors applicable at the probability level of 0.01%.
* Attenuation distribution approximated by a power-law model.

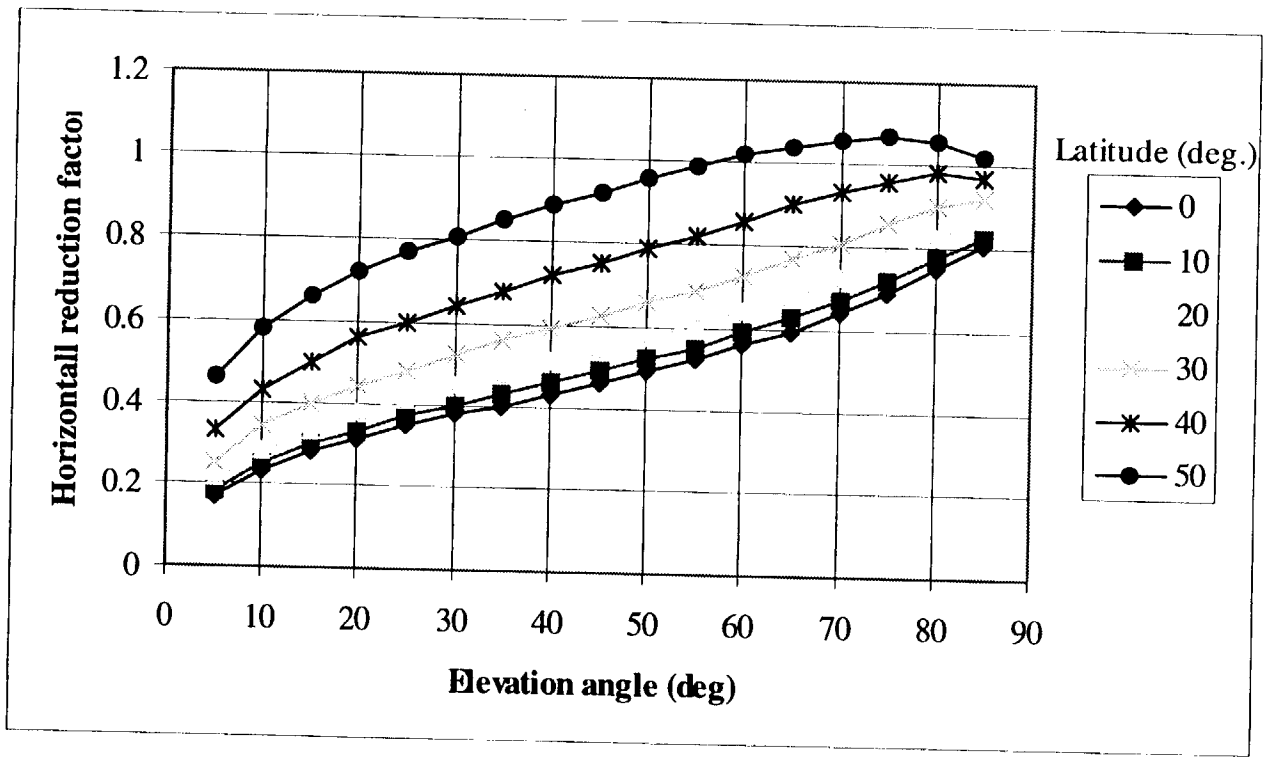
Horizontal Path Adjustment Factor

* Horizontal path adjustment factor best described as a function of specific attenuation, frequency, and the horizontal projection of the rainy path length.

* Shape of the path adjustment factor derived using the statistical model and the parameters describing the shape derived from the terrestrial attenuation database.

* Horizontal projection of the path is multiplied by the adjustment factor to obtain the effective horizontal path length.

Horizontal path adjustment factor at 20 GHz



23 October 1998

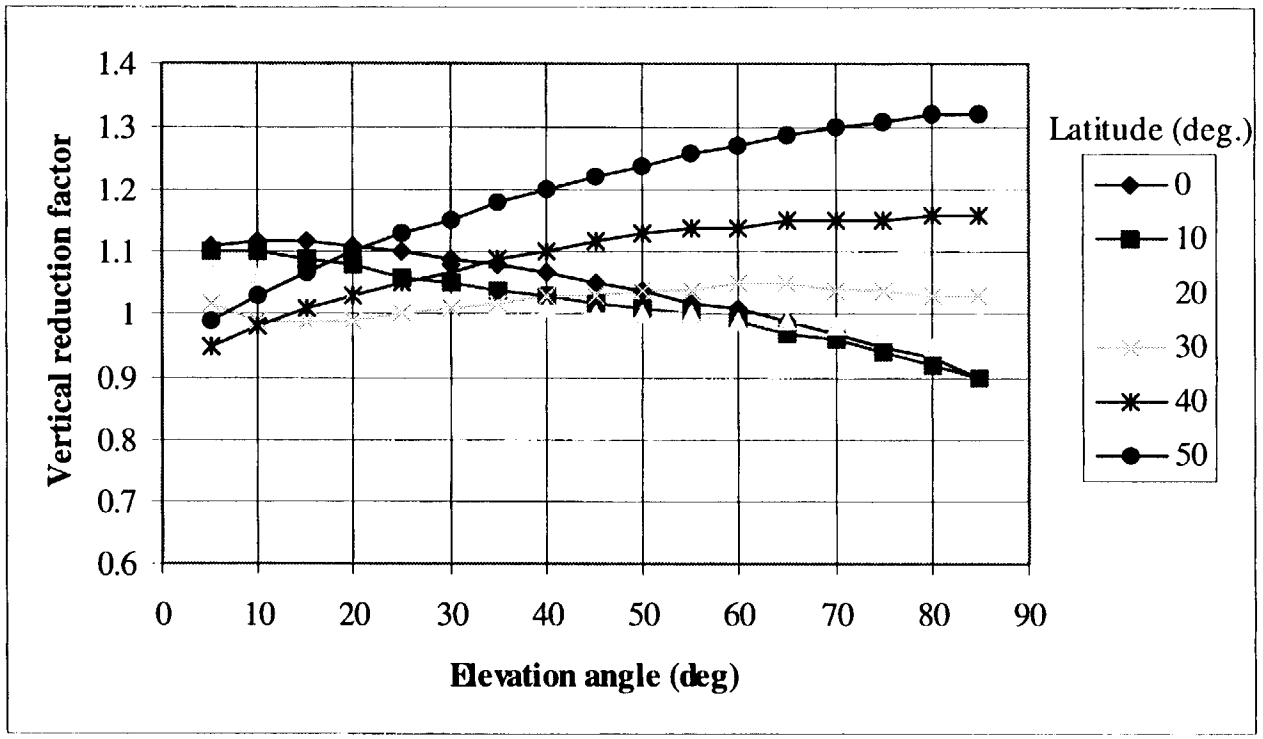
Vertical Path Adjustment Factor

* Vertical adjustment factor applied to 0° C isotherm height; based on measured slant path attenuation data.

* Vertical adjustment factor is a function of frequency, specific attenuation, elevation angle, latitude, and the horizontally adjusted path length.

* After applying the two adjustment factors, effective path length is the distance across the box defined by the adjusted horizontal and vertical path lengths.
A constant specific attenuation along the effective path length assumed.

Vertical path adjustment factor



Rain Model

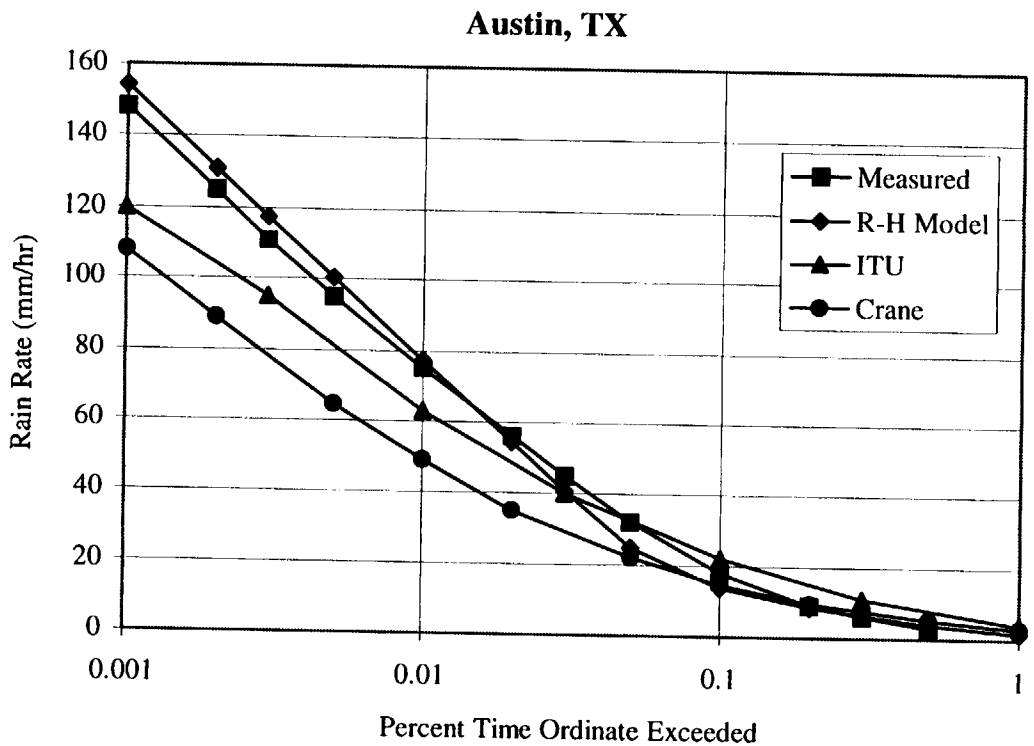
* For satellite link design a rain model based on local rain data is preferred.

* Zonal descriptions are appropriate for planing and coordination purposes.

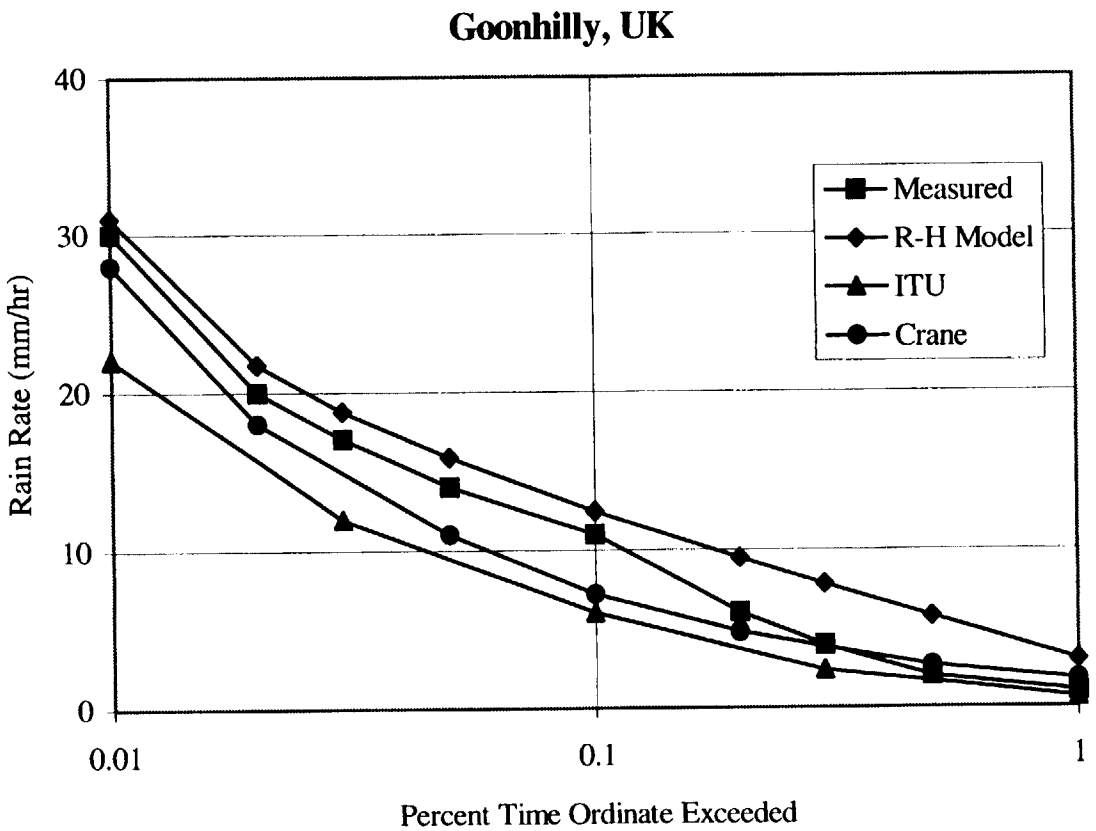
* DAH model appears to provide reasonable predictions when used with the Rice-Holmberg rain model.

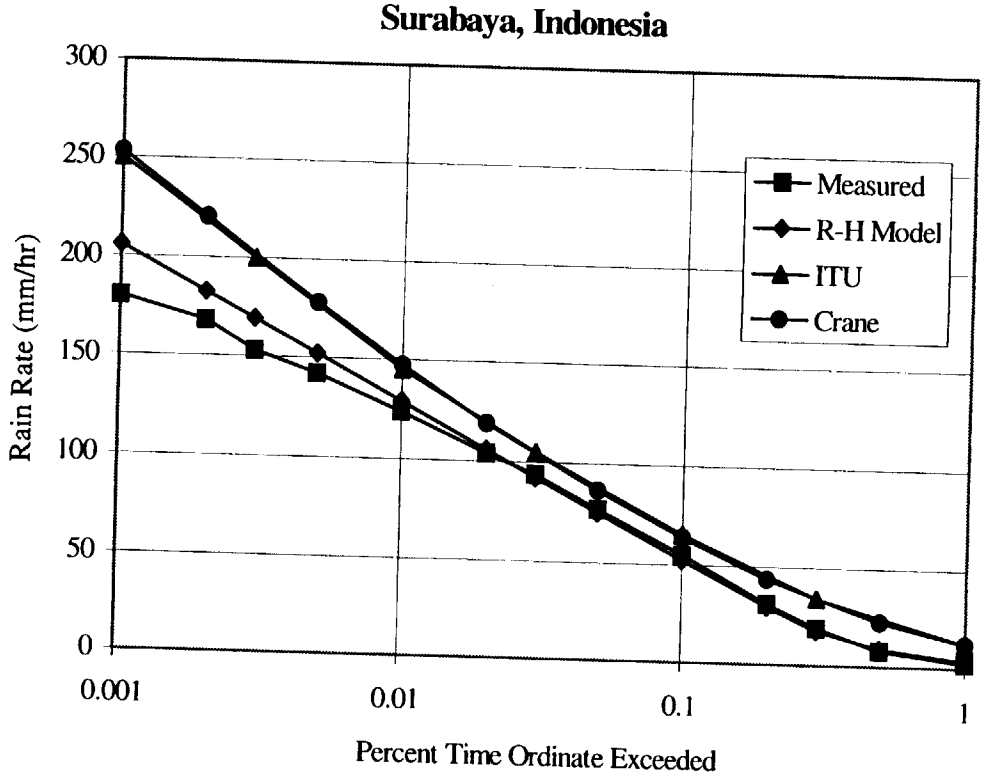
* Parameters for the Rice-Holmberg model (annual rain accumulation and thunderstorm factor) can be easily obtained from climatological data archives.

Rain Model Comparisons



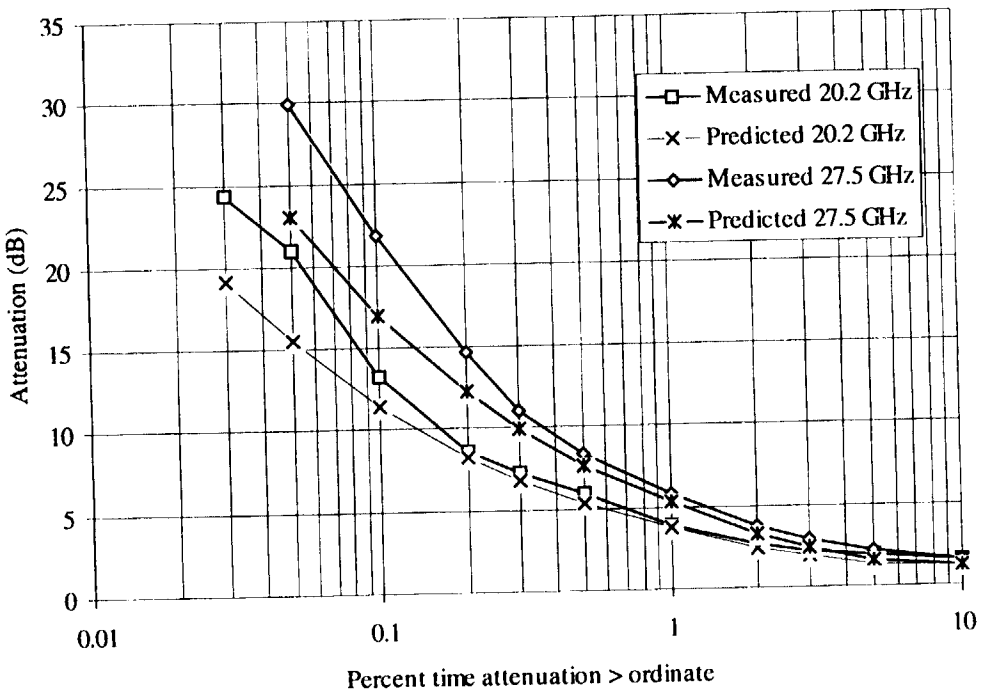
23 October 1998


Goonhilly, UK
40
30
20
10
0
Rain Rate (mm/hr)
0.01
0.1
1
Percent Time Ordinate Exceeded
Measured
R-H Model
ITU
Crane

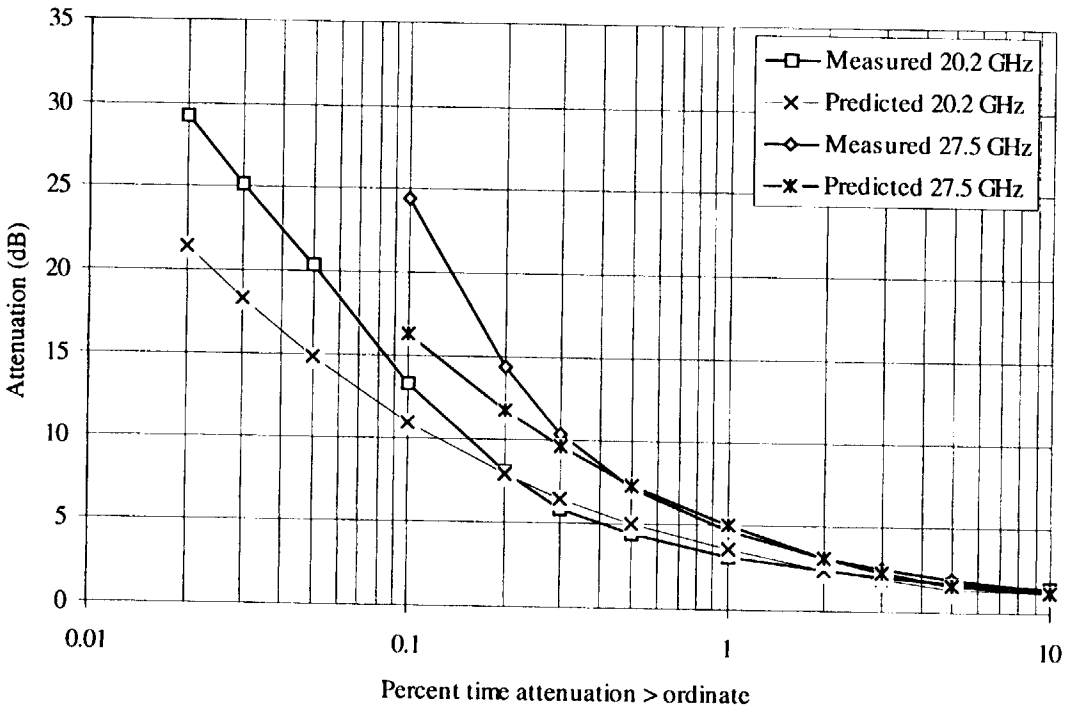

Surabaya, Indonesia
300
250
200
150
100
50
0
Rain Rate (mm/hr)
0.001
0.01
0.1
1
Percent Time Ordinate Exceeded
Measured
R-H Model
ITU
Crane

Attenuation Model Comparisons

- Combined attenuation for Clarksburg, MD



- Combined attenuation for Reston, VA



Conclusions

* A simple rain attenuation prediction model based on the log-normal hypothesis developed.

* Slant-path case is treated as an extension to the terrestrial path prediction.

* Prediction accuracy depends on the availability of representative rain intensity data.

* DAH model provides a method of combining different propagation impairments.

Propagation Effects Handbook for Satellite Systems Design

Louis J. Ippolito
Stanford Telecom

ELEVENTH ACTS PROPAGATION STUDIES WORKSHOP

October 23, 1998
Oklahoma City, OK

ACS Stanford Telecom

Basic Goals for Revised NASA Propagation Handbook

- Combine Scope of the Previous Two NASA Handbooks into a Single Comprehensive Document
- Eliminate Duplication
- Provide a More Cohesive Structure for the Reader
  - Offer Several Levels of "Entrance" into Handbook
- Include Tailored Propagation Analysis Procedures For Specific Types of Satellite Applications

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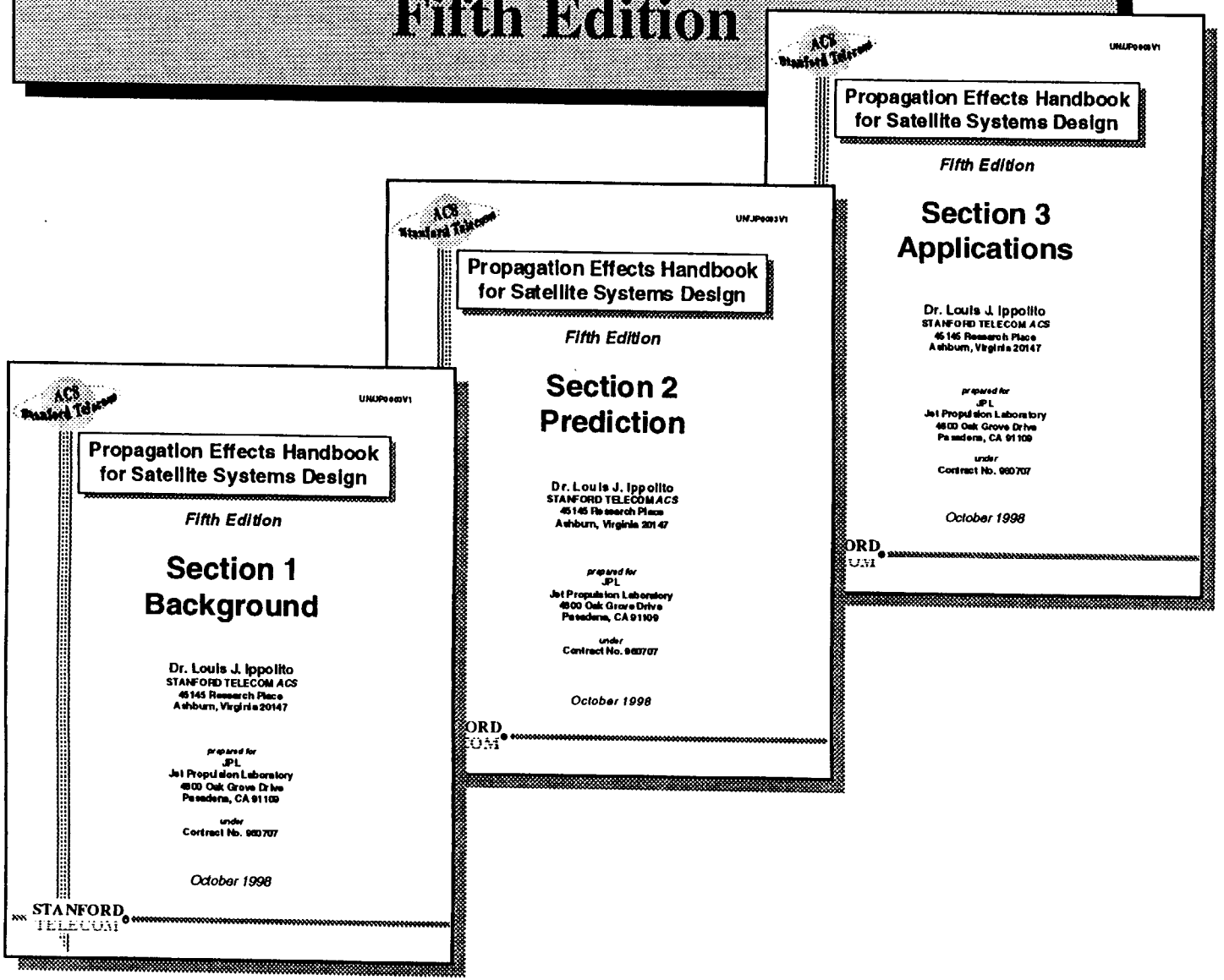

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Basic Structure of Handbook

Three Sections

SECTION 1 BACKGROUND

Provide Overview of Propagation Effects, including Theory and Basic Concepts, Propagation Measurements, Available Data Bases.

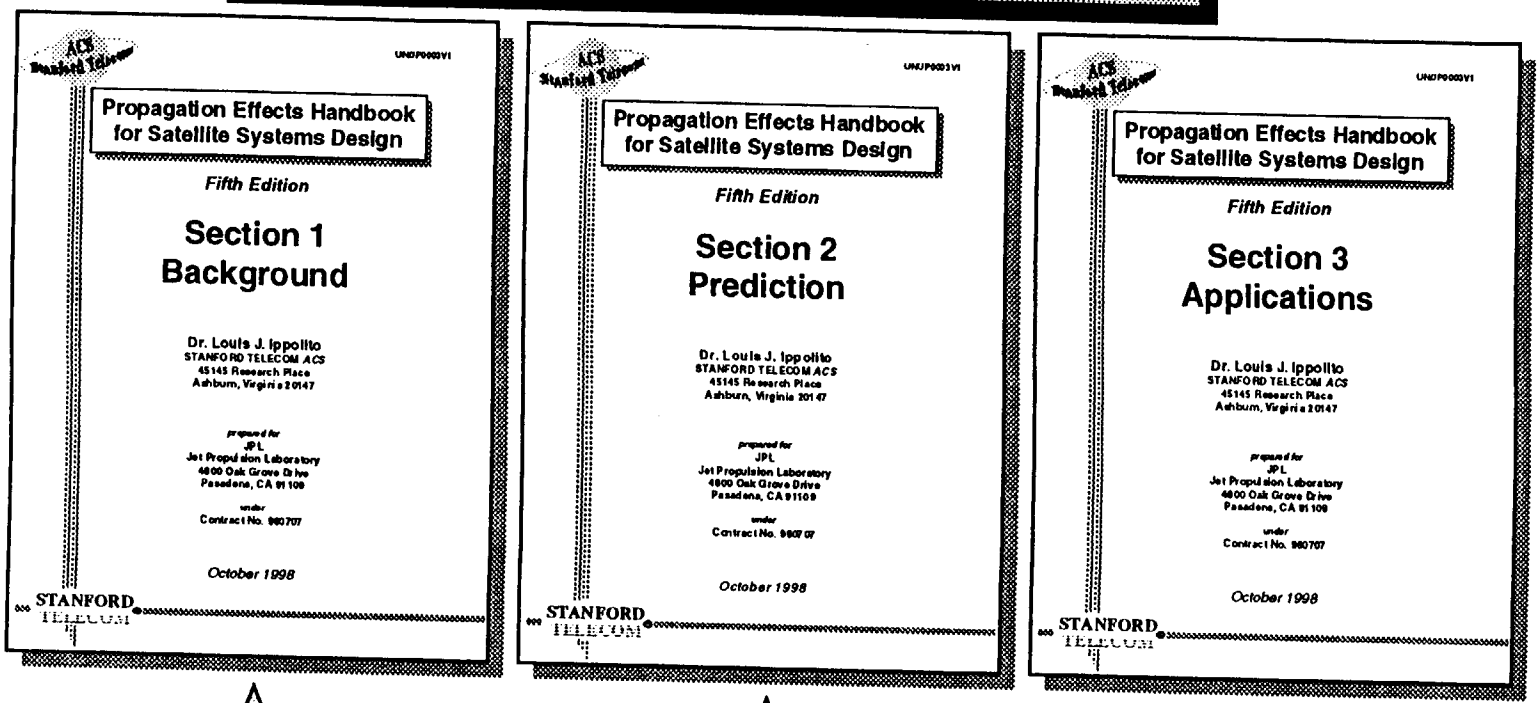
SECTION 2 PREDICTION

Provide Descriptions of Prediction Models and Techniques, Organized By Effect. Provide Step-by-Step Procedures For Each, Where Appropriate. Include Sample Calculations.

SECTION 3 APPLICATIONS

Provide "Roadmaps" {i.e. flow charts} of Application of Prediction Models in SECTION 2 to Specific Satellite Systems and Applications. Include Evaluation and Impact on Systems Design and Performance. Include Sample Calculations.

Three Section Structure



Researcher, General Interest *Enters Here*

Link Analyst *Enters Here*

Systems Designer *Enters Here*

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Fifth Edition Handbooks

- **Section 1 Background**
  - **Six Major Subsections** — **118 pages**
- **Section 2 Prediction**
  - **Six Major Subsections** — **226 pages**
- **Section 3 Applications**
  - **Eight Major Subsections** — **43 pages**
  - **387 pages**

Handbook Highlights

Propagation Effects Handbook for Satellite Systems Design

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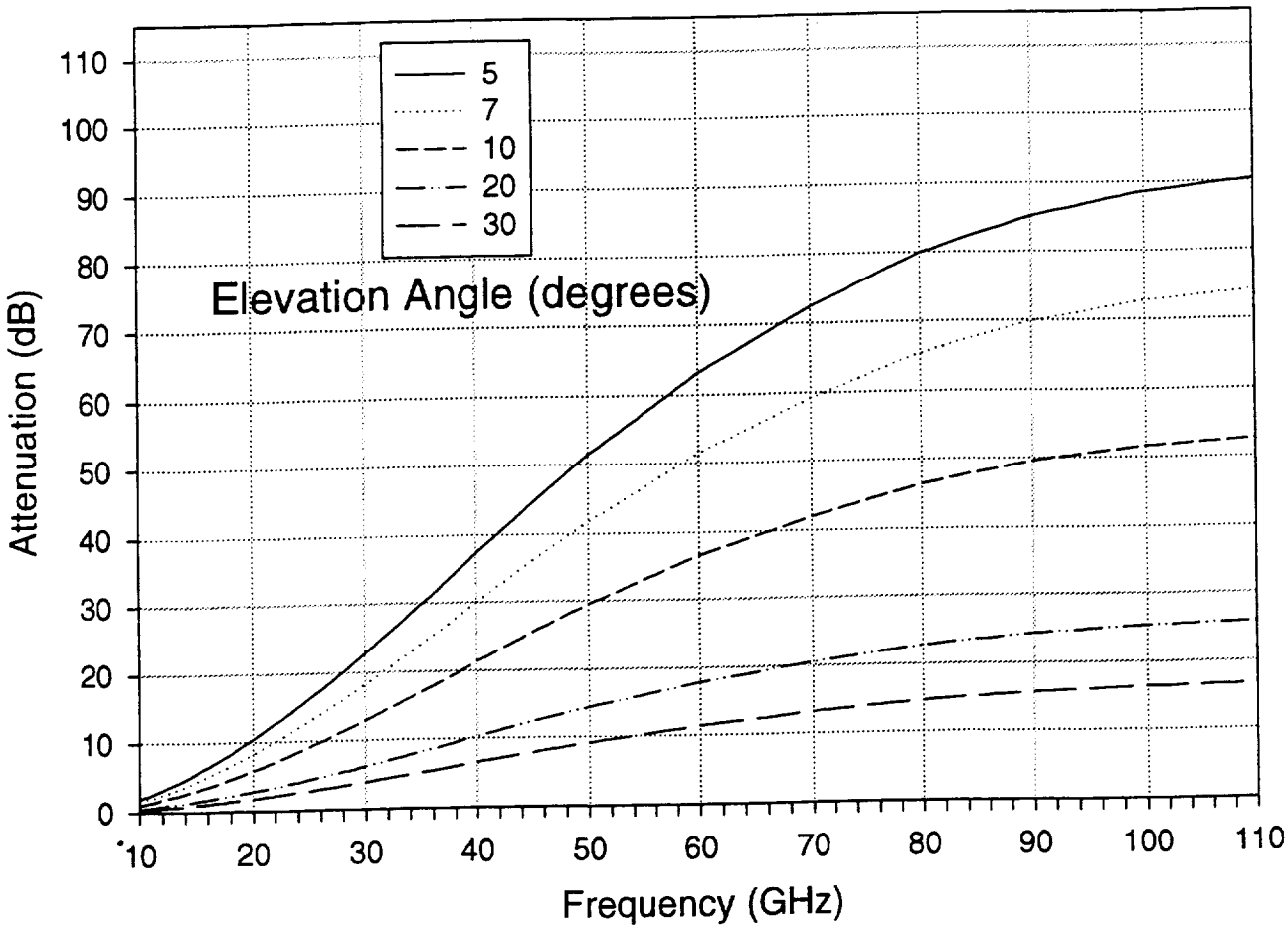

Exhibit1.3.3.2-2
Total path rain attenuation as a function of frequency and elevation angle
Location: Washington, DC
Availability: 99%
Prediction Model: Crane Global Model (see Section 2.2.4.2)

For most rain depolarization prediction models, semi-empirical relations can be used for the U and V coefficients. An example of the application of a rain depolarization prediction model is shown in Exhibit 1.3.3.4-3. The exhibit shows cross polarization discrimination, XPD, as a function of frequency and elevation angle. The curves are for a ground terminal in Washington, DC, and the link availability was set at 99%. The Chu Model (Section 2.2.5.1.1) was used for the calculations.

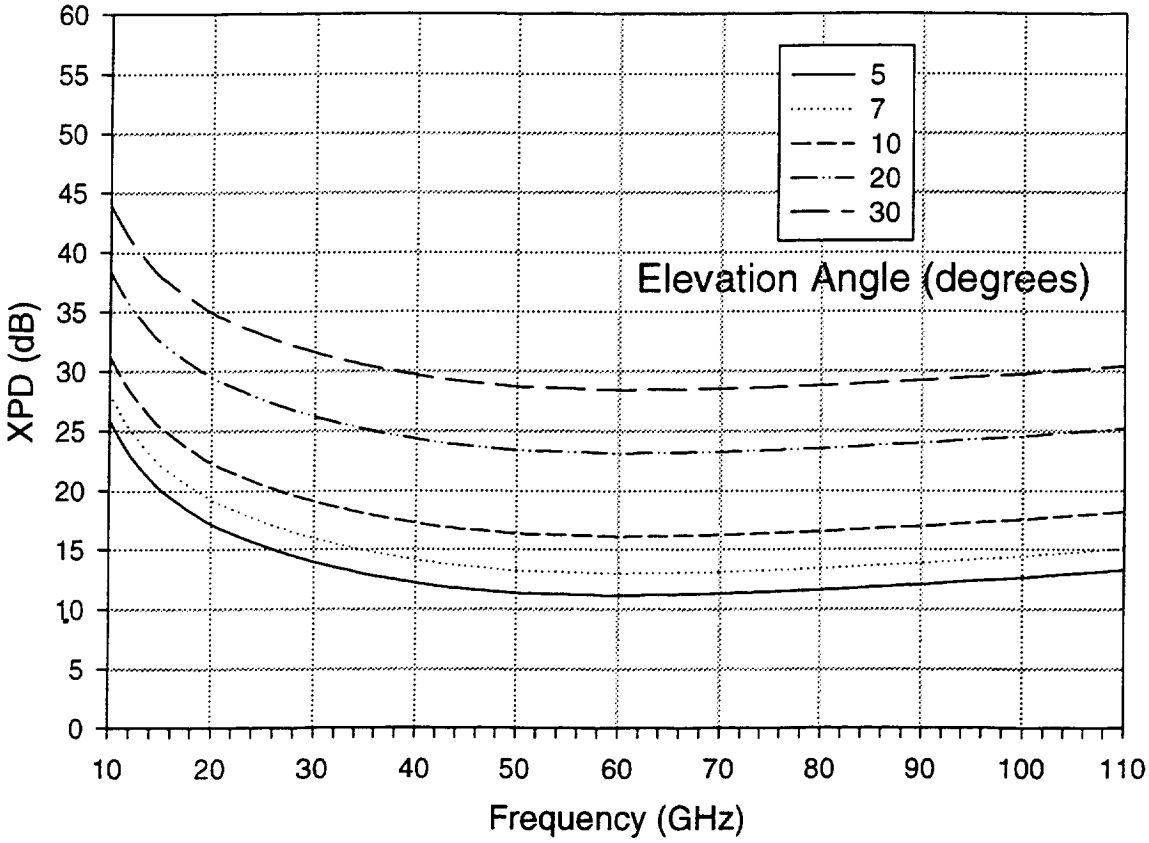

Exhibit 1.3.3.4-3
Rain Depolarization XPD as a function of frequency and elevation angle
Location: Washington, DC
Availability: 99%
Prediction Model: Chu Semi-Empirical Model (see Section 2.2.5.1.1)

Several models and procedures for the prediction of rain depolarization are provided in Section 2.2.5 of this handbook.

Propagation Effects Handbook for Satellite Systems Design

Section 2 Prediction

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2.2.4.1 ITU-R Rain Model

The ITU-R rain attenuation model is the most widely accepted model by the international propagation community. The model was first accepted globally in 1982 and is continuously updated as rain attenuation modeling is better understood. The current model has been deliberately kept simple for ease of use. This section describes the ITU-R model as described in the latest version of Recommendation ITU-R P.618-5, (1997).

The input parameters required for the ITU-R Rain Model are:

f: the frequency of operation, in GHz
2: the elevation angle to the satellite, in degrees
v: the latitude of the ground station, in degrees N or S.
h_s: the altitude of the ground station above sea level, in km.

The step by step procedure follows:

1) Calculate the effective rain height h_{fr} from the latitude of the ground receiver site using the ITU-R rain height procedure.

The freezing rain height (or 0 °C isotherm) is the upper atmosphere altitude at which rain is in the transition state between rain and ice. The rain height is defined in km above sea level. Rain height is calculated as a function of ground station latitude (φ). The rain height, latitude and elevation angle are then used to calculate the slant path L_S through a rain cell and the horizontal component of the slant path L_G.

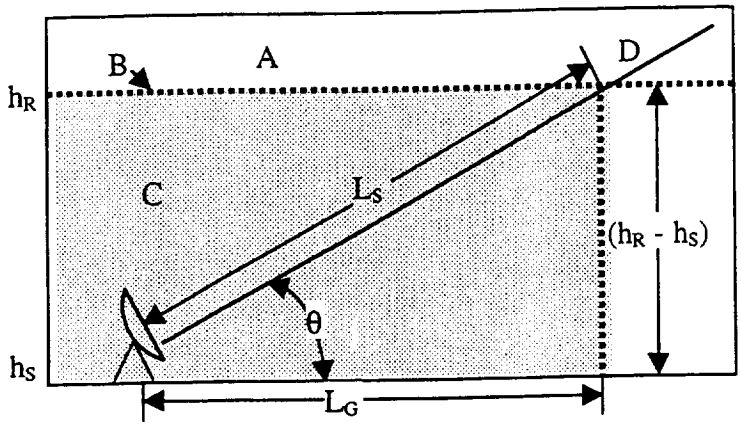
The ITU-R rain height assumes that the rain height, is a function of latitude (φ). The rain height h_R is found as follows:

$$h_R(\varphi) = \begin{cases} 5 - 0.075(\varphi - 23) & \text{for} \quad \varphi > 23^\circ \\ 5 & \text{for} \quad -21^\circ \le \varphi \le 23^\circ \\ 5 + 0.1(\varphi + 21) & \text{for} \quad -71^\circ \le \varphi \le -21^\circ \\ 0 & \text{for} \quad \varphi < -71^\circ \end{cases} \qquad (2.2.4.1\text{-}1)$$

where φ is the latitude of the ground station receiver. Positive φ corresponds to the Northern Hemisphere, and negative φ corresponds to the Southern Hemisphere. The rain height is expressed in km and is expected to be a value greater than zero. The model is only valid for latitudes (φ) less than 89.6° (or greater than -89.6°).

2) Calculate the slant-path length, L_S, and horizontal projection, L_G, from the rain height and the altitude of the ground receiver site.

Rain attenuation is directly proportional to the slant path length. The slant path length L_s is defined as the length of the satellite-to-ground path that is affected by a rain cell (see Exhibit 2.2.4.1-1).



A: frozen precipitation
B: rain height
C: liquid precipitation
D: earth-space path

Exhibit 2.2.4.1-1: Slant Path through Rain

The slant path length L_S, expressed in km, is determined from

$$L_S(\theta) = \begin{cases} \dfrac{(h_R - h_S)}{\sin\theta} & for \quad \theta \geq 5° \\ \dfrac{2(h_R - h_S)}{\left[\sin^2\theta + \frac{2(h_R - h_S)}{R_e}\right]^{1/2} + \sin\theta} & for \quad \theta < 5° \end{cases} \qquad (2.2.4.1\text{-}2)$$

where,

h_R = the height of the rain (km), from Step 1
h_S = the altitude of the ground receiver site from sea level (km),
θ = the elevation angle,
R_E= 8500 km (effective earth radius).

For angles greater than or equal to 5°, the slant path length is derived from the geometry from Exhibit 2.2.4.1-1. This equation for L_S can result in negative values when the rain height is smaller than the altitude of the ground receiver site. If a negative value occurs, L_S is set to zero.

The horizontal projection is calculated as

$$L_G = L_S \cos\theta \qquad (2.2.4.1\text{-}3)$$

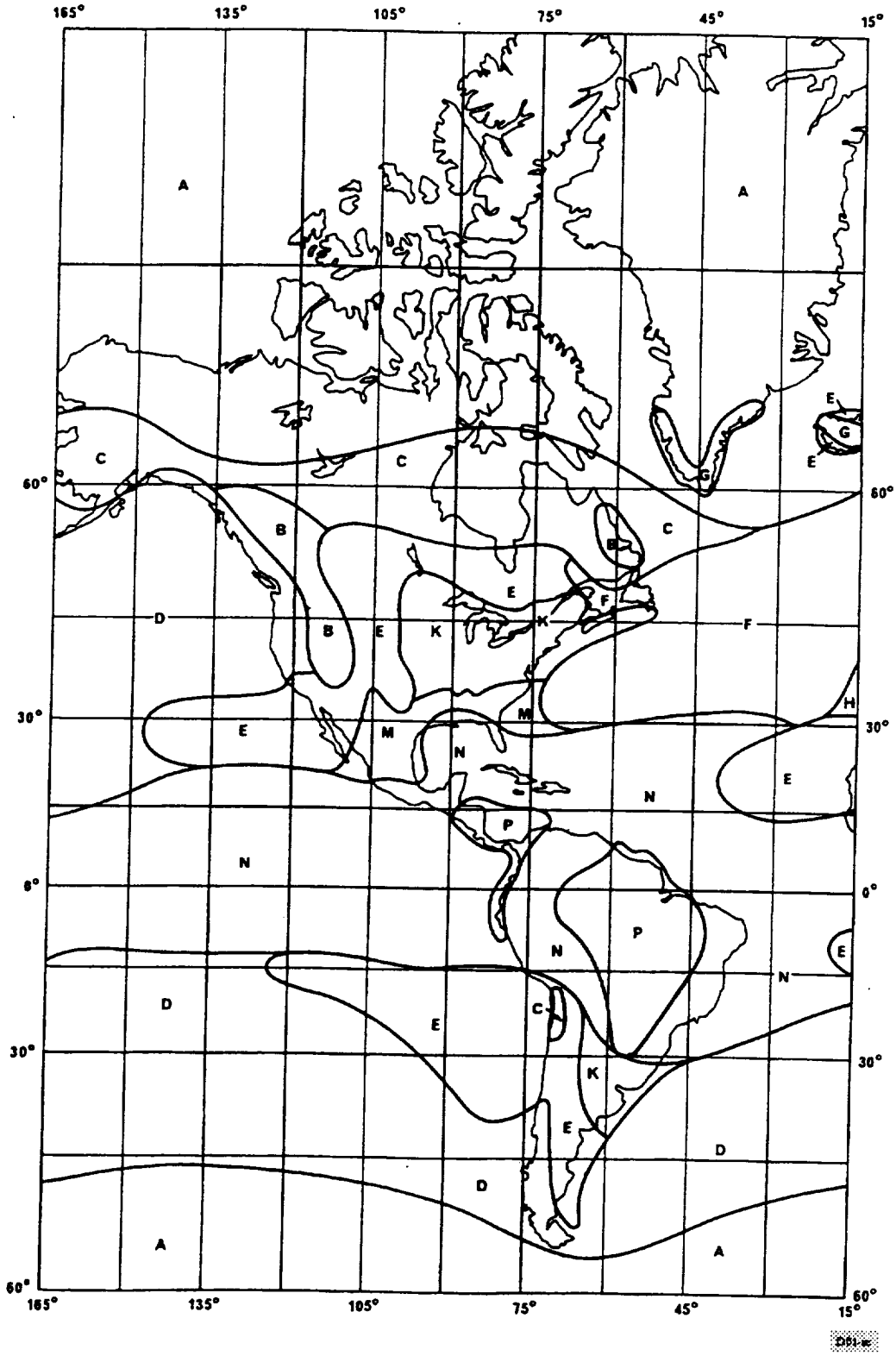


Exhibit 2.2.4.1-3. ITU-R North & South America Rain Regions

2.2.7.2.2 Attenuation Due to Water on the Feed

The principles applied for the smooth conductor case, can also be applied to predict attenuation due to a wet feed. Crane and Ramachandran are currently working to apply these principles to the ACTS feed, the boundary conditions are determined by a four medium interface, illustrated in Exhibit 2.2.7.2-6.

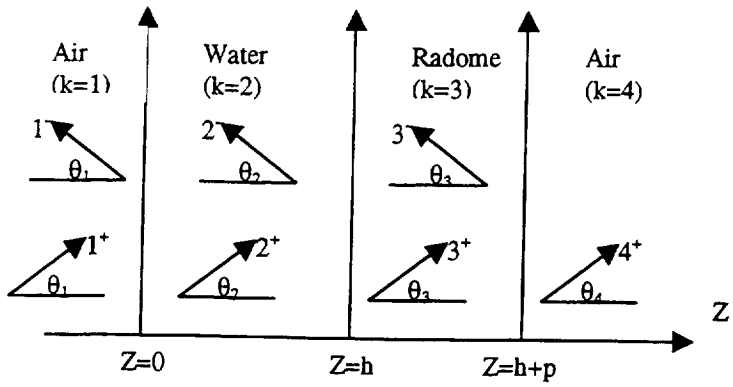


Exhibit 2.2.7.2-6: Boundary Conditions for Water on the Antenna Feed.

Since the derivation and output equations from this method are extremely complicated, the derivation will not be described here. However, Crane and Ramachandran have conducted some simulations using this method. The results are illustrated in Exhibit 2.2.7-7.

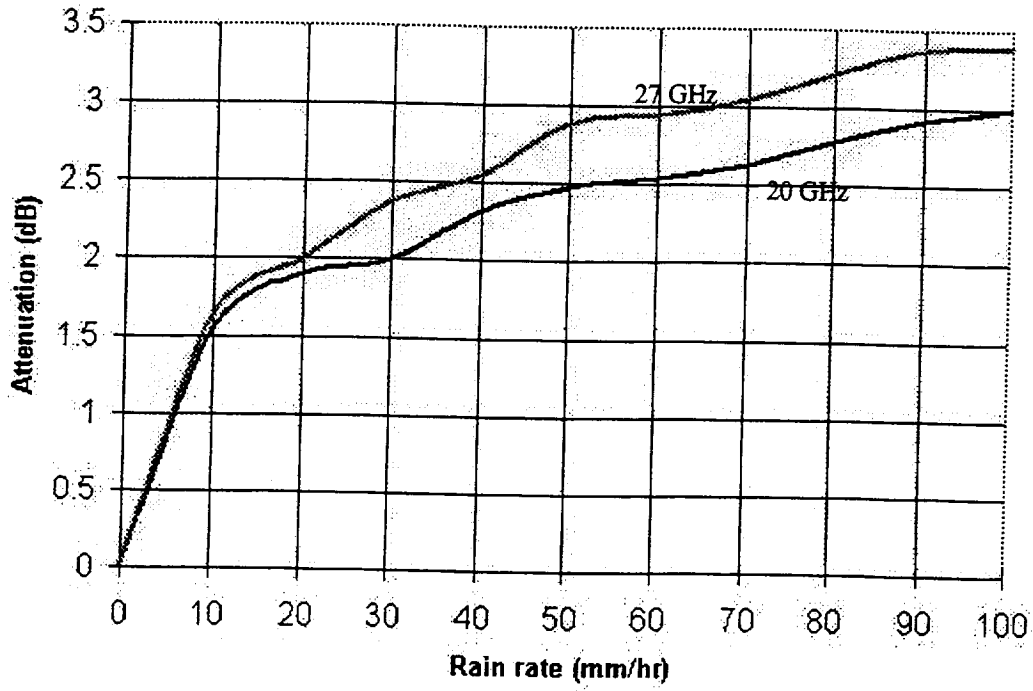


Exhibit 2.2.7.2-7: Attenuation Due to Water on the Feed. (Rain Angle $\alpha = 20°$)

2.2.8.1.3 Scintillation Dynamics

For many low elevation angle systems, the majority of fades below a desired threshold are scintillation induced. Exhibit 2.2.8.1-1 illustrates a scenario in which the mean fade level caused by gas and clouds is above the given threshold, but the strongest scintillations cause short outages.

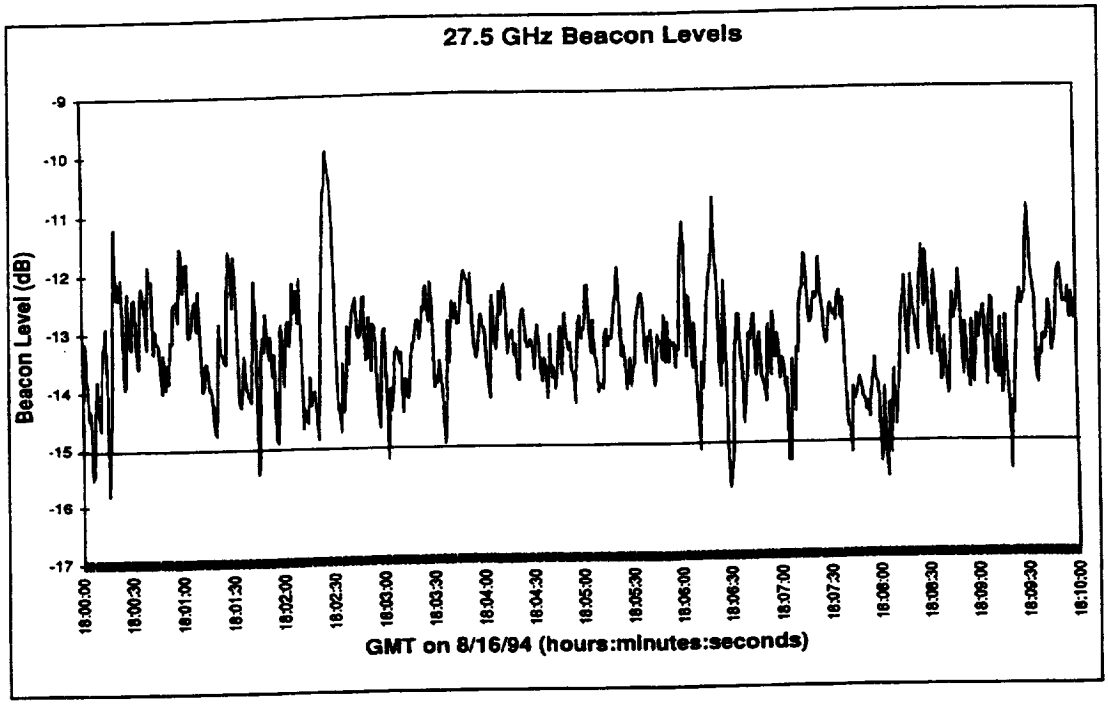


Exhibit 2.2.8.1-1

Beacon Data from Alaska ACTS Terminal (Elevation Angle 8°)

The cdf's for signal fade levels due to combined atmospheric effects are used to estimate the percentage of time a signal will fall below a given threshold, but static cdf's alone do not provide information on the frequency of fade/scintillation occurrence.

The frequency of fade and mean fade duration can be estimated using the static cdf and the well known "level crossing formula" where the expected fade rate of a normal random process is computed from the pdf and the power spectral density function of the process.

The model for estimating frequency of fade, which will be described in this section, was developed at Stanford Telecommunications and presented at the 1996 IEEE / URSI conference in Baltimore, Maryland (Weinfield, J. and T. Russell, 1996).

2.5.1.5 ITU-R Diversity Improvement – Sample Calculation

Considering the theoretical system in section 2.5.1.2 where:

frequency: 20 GHz,
elevation angle: 20°,
availability: 99.9%,
latitude: 38.4°N,
rain region: K, and
attenuation: 11.31 dB

with a second, identical site located at:

D = 10 km and
$\Phi = 85°$,

the diversity improvement factor, I, may be calculated.

Step 1: Calculate the empirical coefficient, β^2

$$\beta^2 = 10^{-4} \cdot D^{1.33} = 10^{-4} \cdot 10^{1.33} = 2.14 \cdot 10^{-3}$$

Step 2: Calculate the diversity improvement factor, I

where P_1 = 100-Availability = 0.1.

Therefore, for a system with an overall attenuation threshold of 11.31 dB the addition of the second site improved system availability from 99.90% to:

Plots of diversity improvement factor, I, for various separation distances are presented in Exhibit 2.5.1.5-1.

Propagation Effects Handbook for Satellite Systems Design

Section 3
Applications

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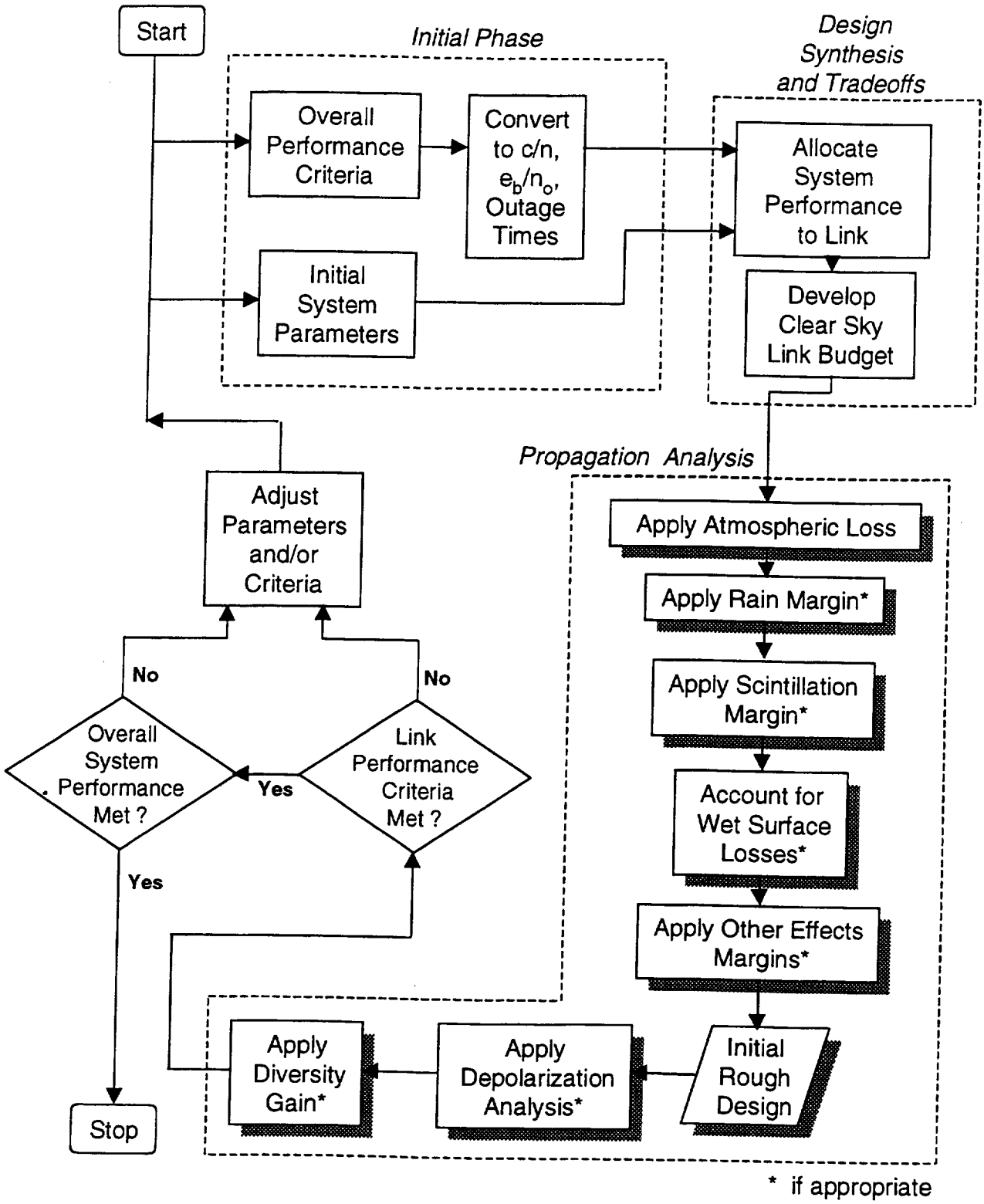

Exhibit 3.1.1-1
System Design Process

Model	ITU-R Evaluation		ACTS Evaluation	
	Overall	15 – 35 GHz	20 GHz	27 GHz
DAH	1	2	1	1
ITU-R	2	3	3	4
ExCell	3	8	2	2
Japan	4	5	8	8
Brazil	5	6	6	6
CCIR	6	7	5	5
Leitao-Watson	7	4	11	11
Misme-Waltdeufel	8	10	N/A	N/A
Two-Component	9	9	4	3
Spain	10	1	9	9
Global	N/A	N/A	7	7
SAM	N/A	N/A	10	10

Exhibit 3.1.3
Comparison of Performance of Rain Attenuation Predicion Models
[Source: Felkhake & Ailes-Sengers, 1997]

The comparisons and rankings are not by any means conclusive, since the range of RMS errors from the highest to the lowest rankings were in the range of 20 to 30 %. There does appear to be a tendency, however, for the DAH, ITU-R, ExCell models to be well performing for all frequency bands.

The recommendations which follow in Section 3 of the handbook will be based for the most part on the results from the comparative studies above. The DAH Rain Attenuation Model (sometimes referred to as the USA Model) is recommended for application to the general link and for a general location. If the reader is interested in specialized conditions, such as low elevation angle, or specific region or frequency of operation, referral to the ITU-R and ACTS studies is highly recommended, where further qualitative breakdowns of the comparisons are provided in great detail.

This recommendation is subject to revision and update as further data and studies become available.

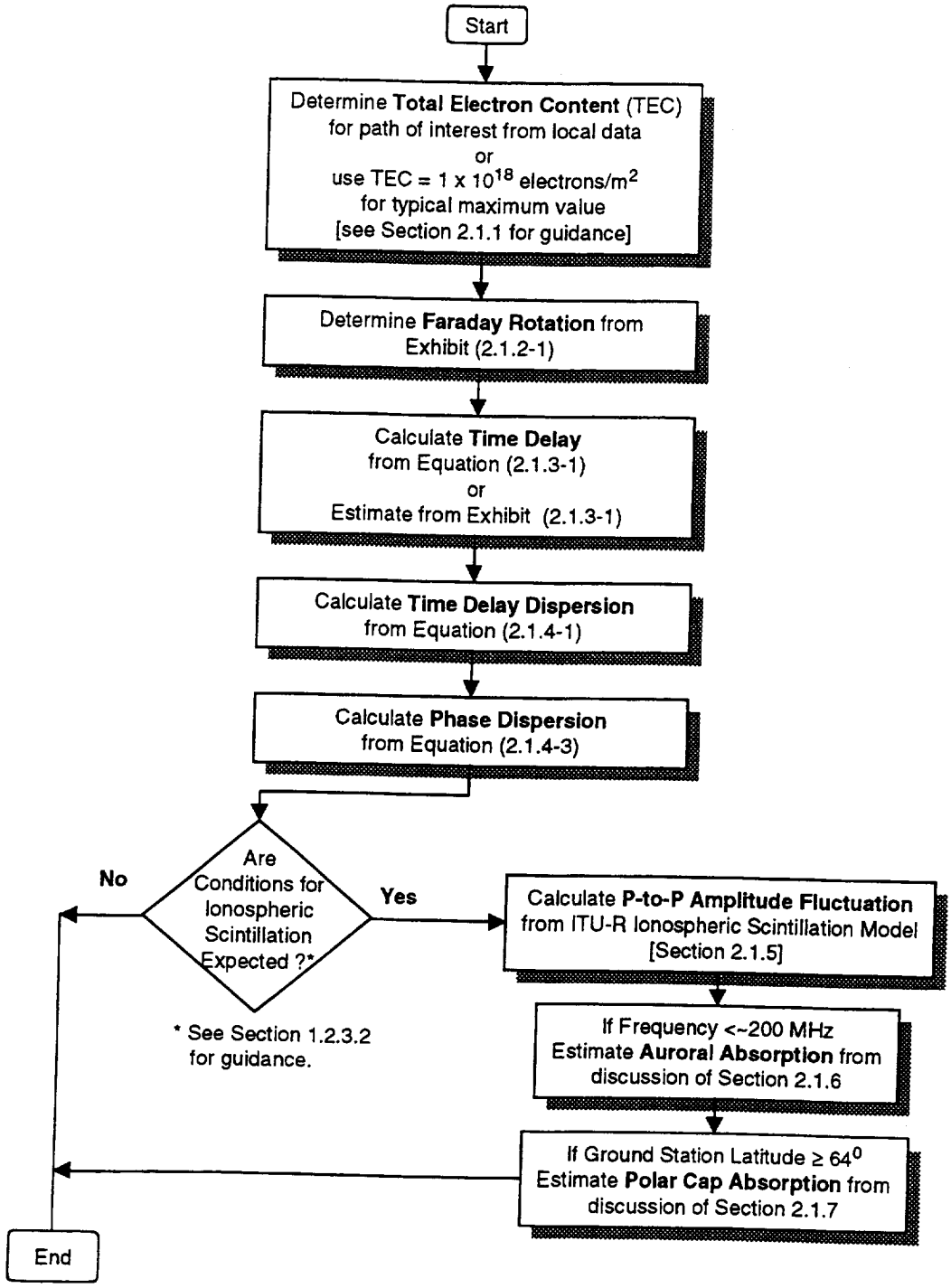

Exhibit 3.2.1-1
Propagation Analysis Procedure for Satellite Links Operating Below About 3 GHz

3.2.2 Mobile Satellite System Service Links

Propagation effects and modeling procedures for the service links of mobile satellite systems are described in companion NASA Handbooks published by Goldhirsh and Vogel (1992, 1998). The reader is referred to those documents for a complete compilation of propagation considerations for vehicular and personal mobile satellite systems operating in the frequency bands from UHF through K-band. This section provides a brief overview of the two documents and the subject areas covered.

Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results, NASA Reference Publication 1274, February 1992.

The first edition of the Handbook describes a systematic set of studies of propagation effects for land mobile satellite system (LMSS) for rural and suburban conditions in the Unites States. UHF and L-band links are included. Measurements were accomplished with a variety of signal sources, including balloons, remotely piloted aircraft, helicopters, and satellites (MARECS-B2, ETS-V, and INMARSAT). The contents of the handbook are:

Chapter

1 Introduction
2 Attenuation Due to Individual Trees: Static Case
3 Attenuation Due to Roadside Trees: Mobile Case
4 Signal Degradation for Line-of-Sight Communications
5 Fade and Non-Fade Durations and Phase Spreads
6 Propagation Effects Due to Cross Polarization, Gain, and Space Diversity
7 Investigations from Different Countries
8 Modeling for LMSS Scenarios

LMSS models are described for roadside shadowing, diversity operation, probability distributions, and object scattering. Extensive references are provided.

The complete handbook can be found on-line at the NASA JPL propagation home page;
http://propagation.jpl.nasa.gov/TOC.html

Propagation Effects for Vehicular and Personal Mobile Satellite Systems: Overview of Experimental and Modeling Results, *Second Edition*, NASA Reference Publication 1274, 1998.

This document provides updated measurements since the first edition and broadens the scope to additional frequency bands and to other mobile service geometries. Measurements at UHF, L-band and K-band are described. Propagation effects for personal communications systems (PCS),

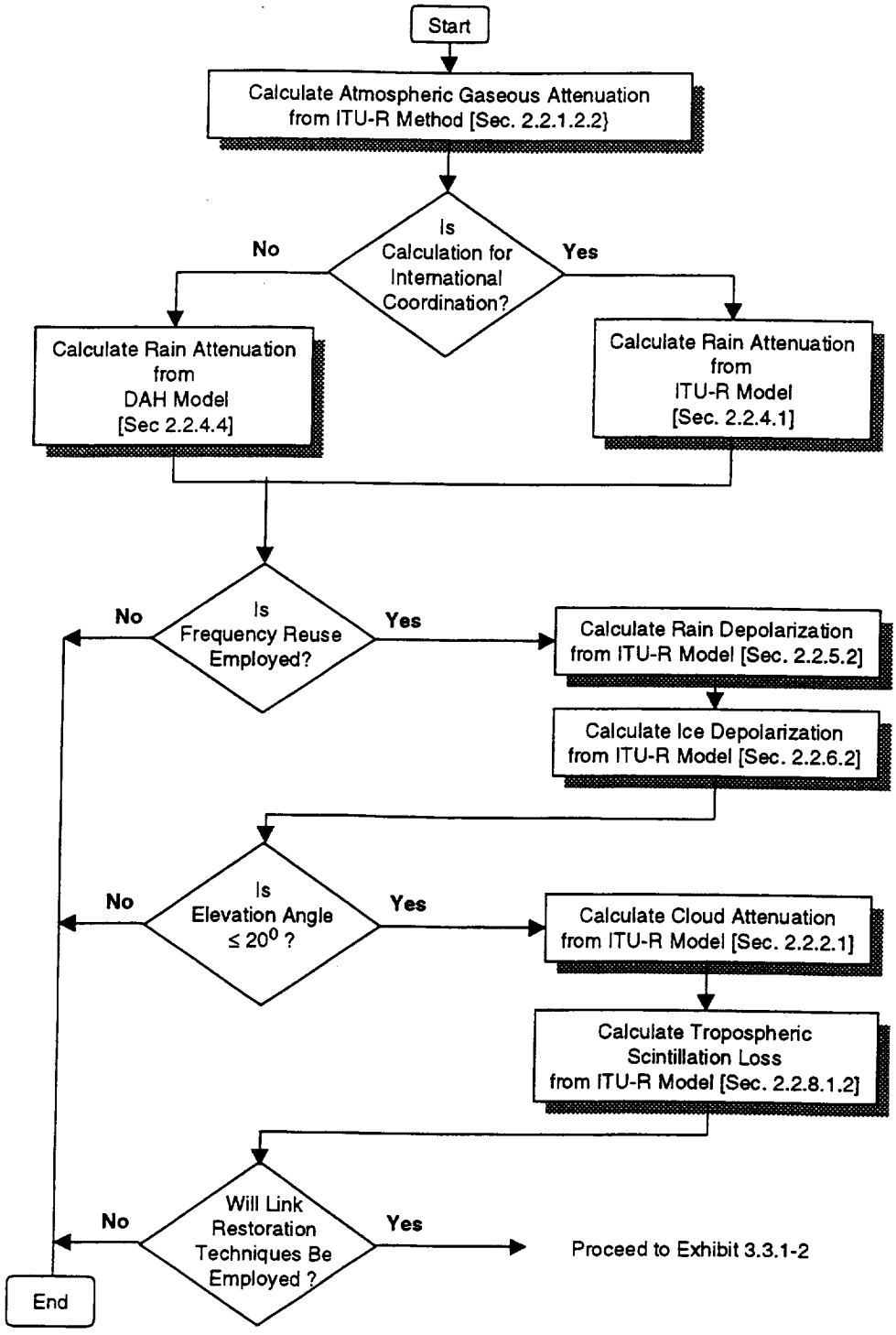

Exhibit 3.3.1-1
Propagation Analysis Procedure for Ku-Band FSS Links

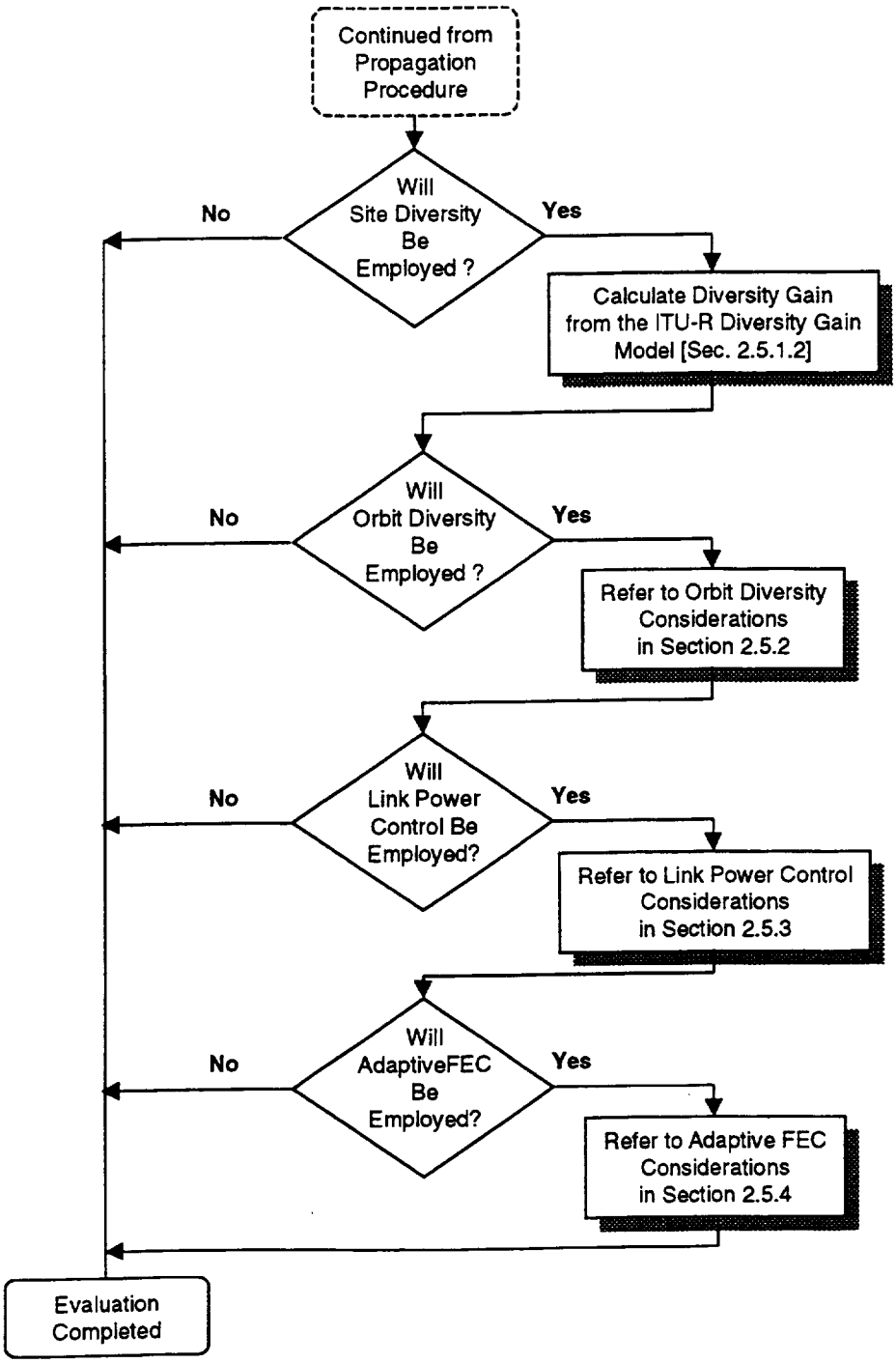

Exhibit 3.3.1-2
Procedure for Evaluation of Link Restoration Techniques

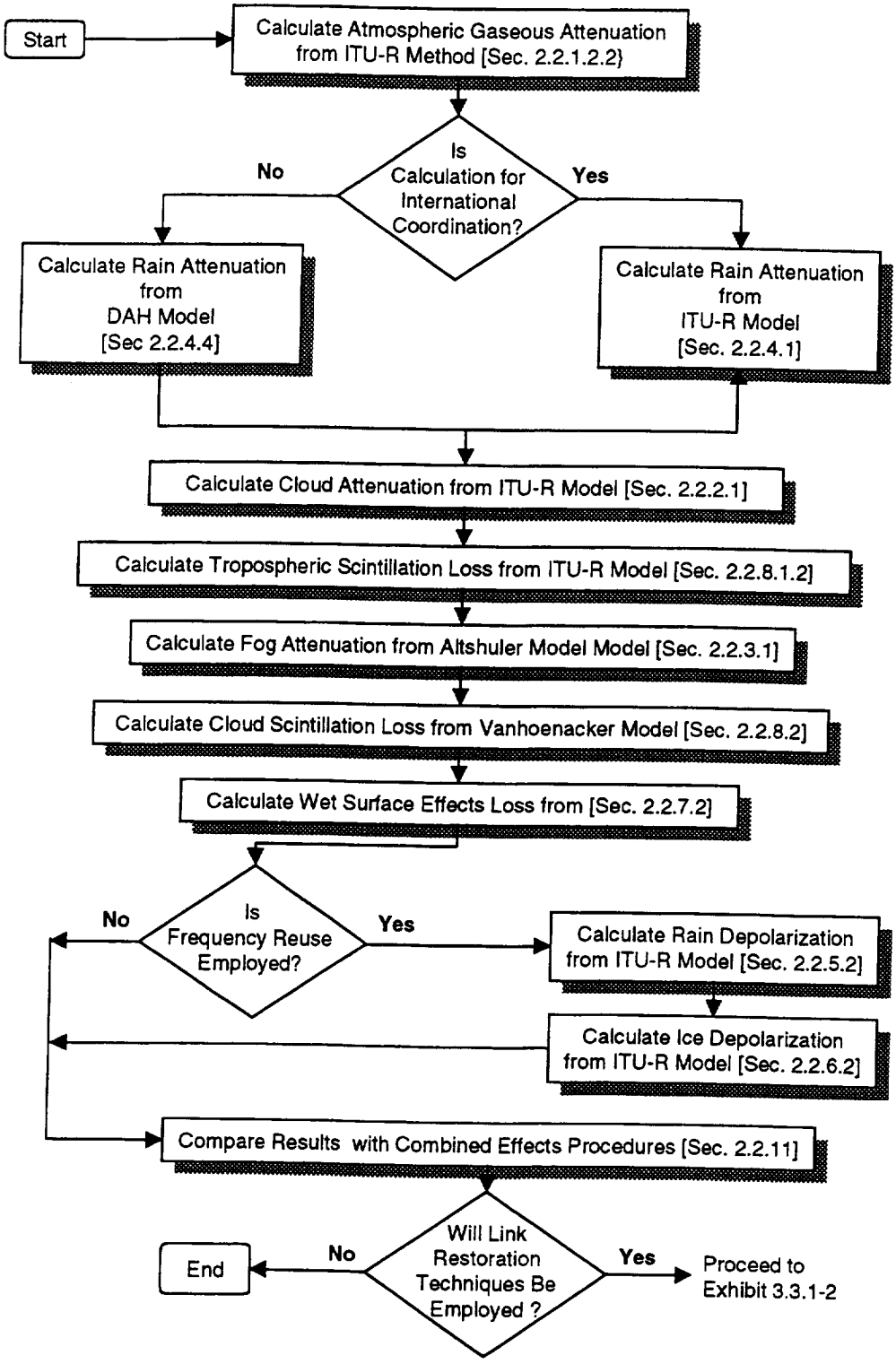

Exhibit 3.4.2-1
Propagation Analysis Procedure for Low Margin Ka-Band Links

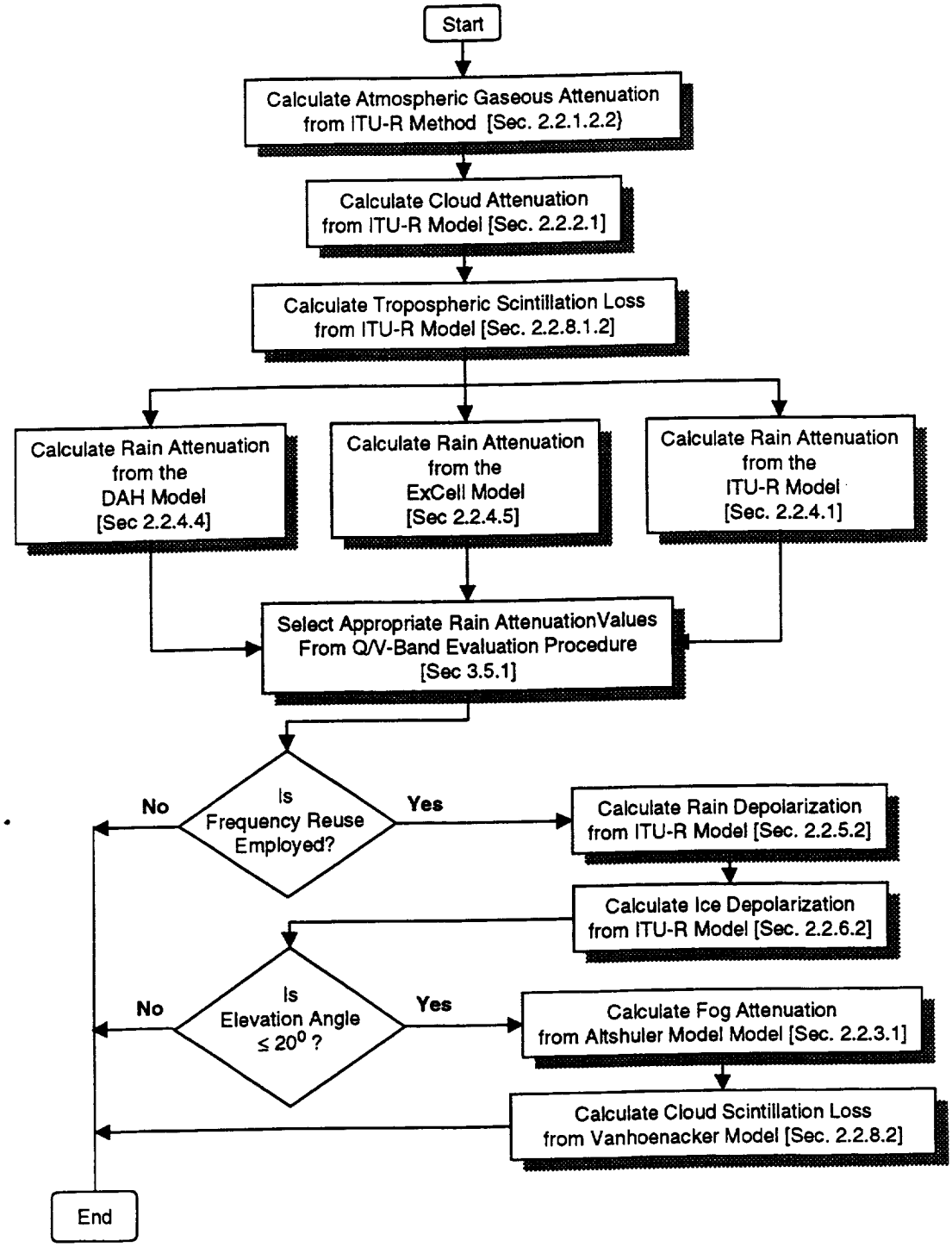

Exhibit 3.5-1
Propagation Analysis Procedure for Q/V-Band Links

Consider a low earth orbit (LEO) satellite in a circular polar orbit at an altitude of 765 km, with and ascending node at 100^0W. This is a typical orbit for a MSS Big LEO satellite. Let us assume the satellite has a feeder link operating in the Ka-band, with a feeder link terminal located at 106.6^0W and 32.5^0N latitude (White Sands, NM). Assume that the 20 GHz downlink has a fixed power margin of 74 dB available for free space path loss and propagation losses.

Exhibit 3.7-1 shows a plot of elevation angle and path loss with time for a single pass of the satellite over the ground terminal. The elevation angle (heavy solid line) reaches a maximum of about 60 degrees. The free space path loss (long dashed line) ranges from 70 dB at the horizon points to a minimum of 59 dB at the center of the pass, where the elevation angle is at the maximum. The light solid line shows the available power margin of 74 dB. The difference between the available margin and the path loss, (shown by the double arrow line), is the margin available for propagation losses. The propagation margin ranges from 4 dB at the horizon points to 15 dB at the midpoint of the pass.

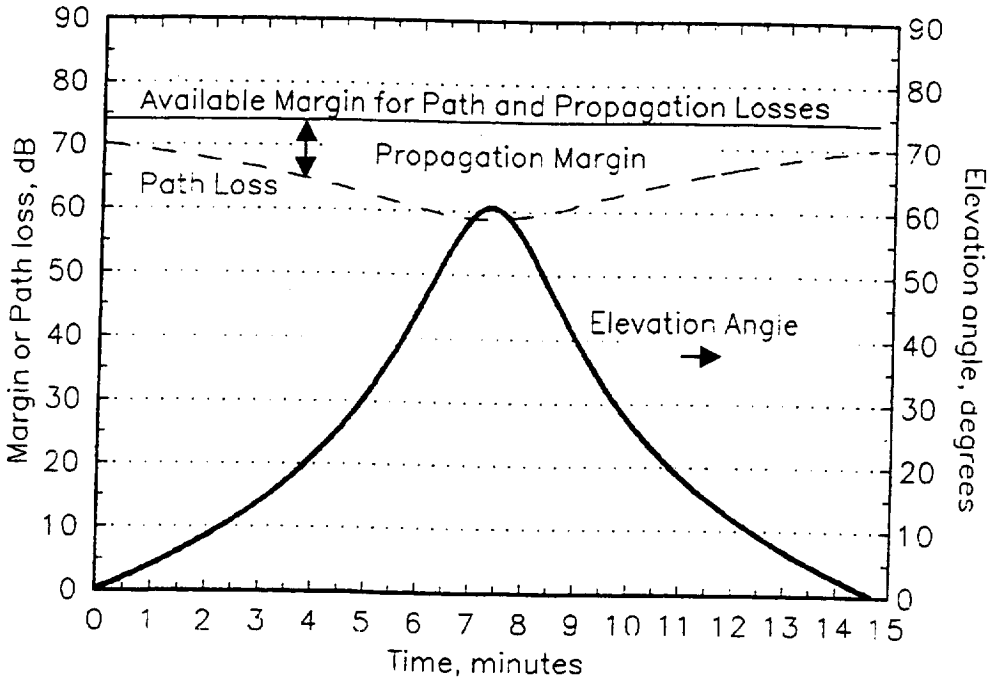

Exhibit 3.7-1
Elevation Angle and Path Losses for a Single Pass of a LEO Satellite
Frequency = 20 GHz, Altitude = 765 km

validates the comment made earlier that the system will have less margin at low elevation angles, where it is most needed.

The next step in the procedure is to determine expected rain attenuation outage statistics for the single pass, from the time variation of the rain margin. The rain attenuation prediction models in Section 2.2.4 of the handbook provide annual statistics of rain attenuation at a fixed elevation angle. The relative reliability at various portions of the LEO pass can be evaluated by applying the rain statistics from a prediction model to the time variable rain margin to determine an equivalent annualized outage probability for the link.

Exhibit 3.7-3 shows the annualized outage probability for the single LEO pass by application of the Global Model [Section 2.2.4.2] to the time varying Rain Margin shown in the previous plot. The ground station location is in Global Model Climate Region F (see Exhibit 2.2.4.2-1).

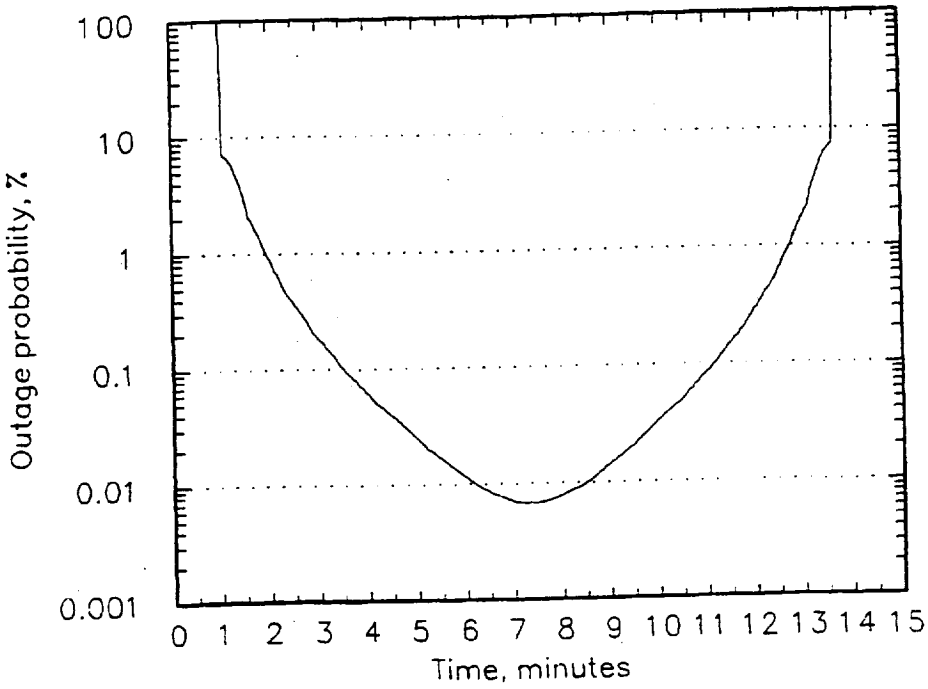

Exhibit 3.7-3
Annualized Outage Probability for a Single Pass of a LEO Satellite
Frequency = 20 GHz
ITU-R Gaseous Attenuation Model [Sec. 2.2.1.2.2]
Global Model [Sec 2.2.4.2]

The result shows that the link has less than 0.01% annual probability of outage (99.99% link availability) for three minutes in the midpoint of the pass. However, the link availability drops to 99% at ± 2 minutes into the pass. The link will not close for about 1 minute at the horizon points.

ACS Stanford Telecom

Status and Future Plans

- Handbook Delivered to JPL October 23 1998
- Electronic Versions on-line
  - JPL
  - Stel
- On-going Peer Review
- Plan for Modifications and Enhancements
  - Revise current Edition
    - Corrections, Minor Changes
  - Develop Sixth Edition
    - Enhancements, Updated Models, New Areas

Highlights of: "Propagation Effects for Vehicular and Personal Mobile Satellite Systems: Overview of Experimental and Modeling Results"

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The Johns Hopkins University
Julius_goldhirsh@jhuapl.edu

Wolfhard J. Vogel
Electrical Engineering Research Laboratory
The University of Texas at Austin
wolf_vogel@mail.utexas.edu

Overview of Handbook

1. Revision of NASA Reference Publication 1274 Previously Entitled:
   (a) Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results
   (b) February 1992

2. New Title:
   Propagation Effects for Vehicular and Personal Mobile Satellite Systems: Overview of Experimental and Modeling Results

3. Comprised of 12 Chapters
   (a) Four are new
   (b) Other chapters updated and enhanced

Overview of Handbook (Continued)

4. Nine chapters have been completed and are on the Web
   (a) Address is:

http://www.utexas.edu/research/mopro/

   (b) Chapters may be downloaded as Adobe files

5. Two chapters have been written and are being edited.

6. Final chapter is being written.

7. Hard copies to be available December 31, 1998
   (a) Disseminated to Workshop and other interested investigators

Overview of Handbook (Continued)

8. Handbook will subsequently undergo review process
   (a) Ernie Smith, Warren Flock, Ken Davies, other volunteers
9. Revised edition will subsequently be published
   (a) Reviewers' comments addressed
   (b) Other readers' comments addressed

Handbook Chapter Titles and Status

Chapter 1: Introduction
(Being edited)

Chapter 2: Attenuation Due to Trees: Static Case
(On the Web)

Chapter 3: Attenuation Due to Roadside Trees: Mobile Case
(On the Web)

Chapter 4: Signal Degradation for Line of Sight Communications
(On the Web)

Chapter 5: Fade and Non-Fade Durations and Phase Spreads
(On the Web)

Chapter 6: Polarization, Antenna Gain and Diversity Considerations
(On the Web)

Status of Handbook (Continued)

Chapter 7: Investigations from Different Countries
(On the Web)

Chapter 8: Earth-Satellite Propagation Effects Inside Buildings
(New: On the Web)

Chapter 9: Maritime-Mobile Satellite Propagation Effects
(New: On the Web)

Chapter 10: Optical Methods for Assessing Fade Margins
(New: On the Web)

Chapter 11: Theoretical Modeling Considerations
(Being written)

Chapter 12: Summary and Recommendations
(Being edited)

Mobile Satellite Handbook Statistics

Chap. #	Number Pages	Number kb	# Pages Prev. Txt
1	6	74	4
2	22	215	10
3	41	402	19
4	21	141	6
5	19	201	11
6	22	172	10
7	42	368	13
8	40	1,357	
9	40	221	
10	25	399	
11	45 (est.)	804 (est.)	41 (Ch. 8)
12	28	1,917	
Total	**351**	**6,270**	**114**

Propagation Models Database

Anil V. Kantak

James Rucker

Jet Propulsion laboratory

California Institute of Technology

Pasadena, California 91109

October 23, 1998.

JPL

PROPAGATION MODELS DATABASE

- A database of various propagation phenomena models which can be used by the telecommunications systems engineers to obtain the desired parameter values for systems design.
- Propagation research
  - Ease of using the models
  - Passing the experimental data through the models
  - Comparison and checking of experimental data.
- An easy to use convenient tool, implemented on a PC to analyze the user propagation data.

AVK
10/23/98

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PROPAGATION MODELS DATABASE

- Salient features of the software:
  - Microsoft Excel 5.0-based software, utilizing Excel's excellent spreadsheet features and charting functions.
  - Every model is written as Excel subroutine / Excel User-Defined Function.
  - The program produces output for the user in its own spreadsheet or the user may use the subroutines / functions in their own Excel program and transport the result to their program.
  - Every care is taken to avoid user-made errors in running the program models.

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PROPAGATION MODELS DATABASE

- Every model of the database has the same overall instructions set and same operating procedure, making the user capable of using any model once the procedure is learned.
- Extensive charting procedures are available to the user and, where feasible, the charting procedures and workings are made transparent to the user. The program allows the user to vary any desired variable of the model and see its effects on the user-selected output variable via a chart. The user is allowed to loop back to obtain other combinations of outputs and independent variables without running the model again.
- Every chart produced may be saved or printed out.

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PROPAGATION MODELS DATABASE

- The database is divided into six major categories
  - Ionospheric propagation models.
  - Tropospheric propagation models.
  - Land-Mobile system propagation models.
  - Effects of small particles on propagation.
  - Rain models.
  - Radio noise models.

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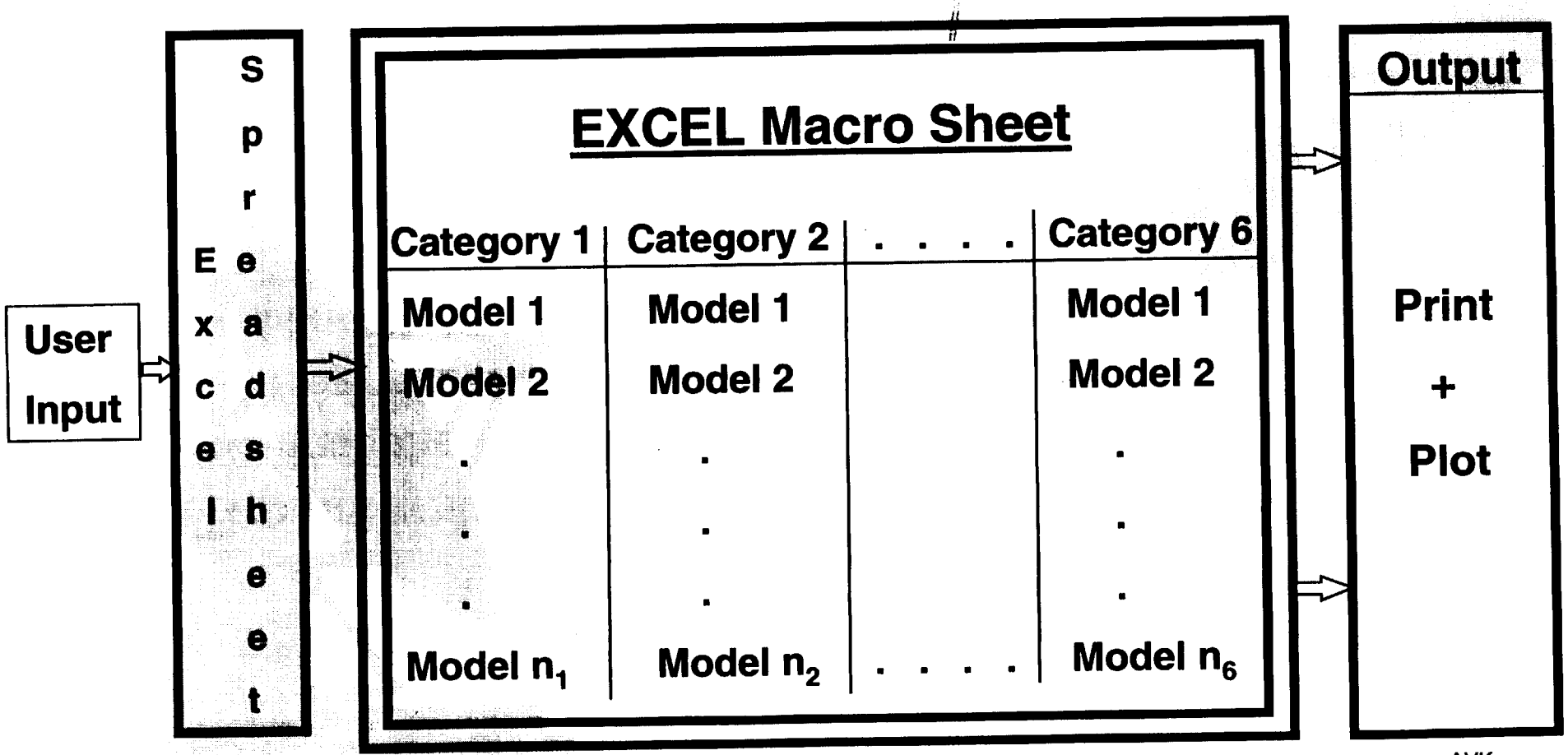
PROPAGATION MODELS DATABASE



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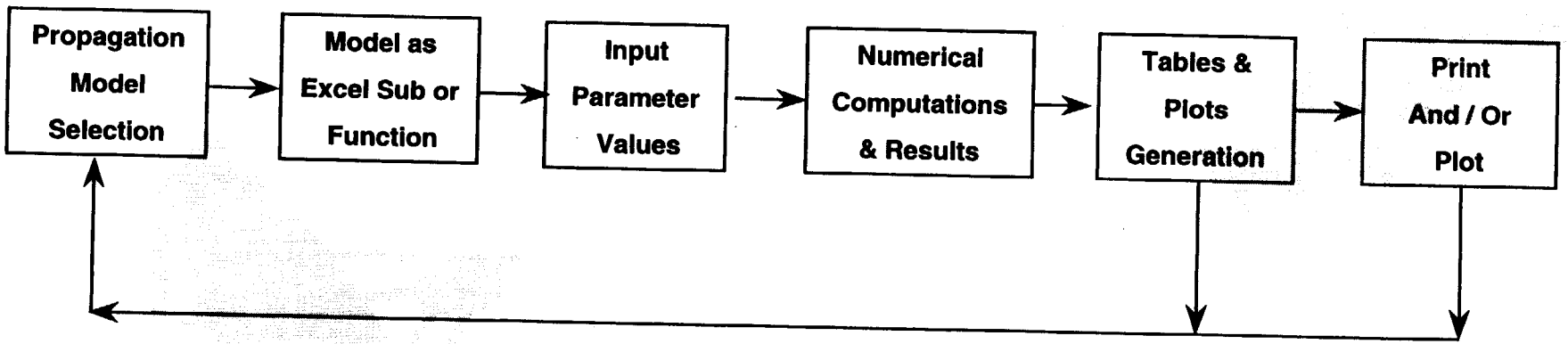

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PROPAGATION MODELS DATABASE

- System Requirement:
  - Windows NT or Windows 95
  - At least 8 to 16 Mbytes of RAM
  - 2 Mbytes of disk space.
  - 486 or Pentium processor with at least 25 MHz clock rate.

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PROPAGATION MODELS DATABASE

- Properties of the current version.
  - Enhanced graphics.
    - Allows the user to produce many different types of graphs from the same vectors.
  - New propagation models added.
  - Enhanced a few existing models.

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PROPAGATION MODELS DATABASE

- Conversion of the Propagation Models Database from Excel environment to C++ environment.
- Design Concepts
  - Isolation of:
    - User Interface
    - Databases
    - Computational Engine.
  - Make the Propagation Database software more compatible with other software the user may have.
  - Make the Propagation Database software independently accessible from a server by remote users.
  - Make the Propagation Database software platform independent.

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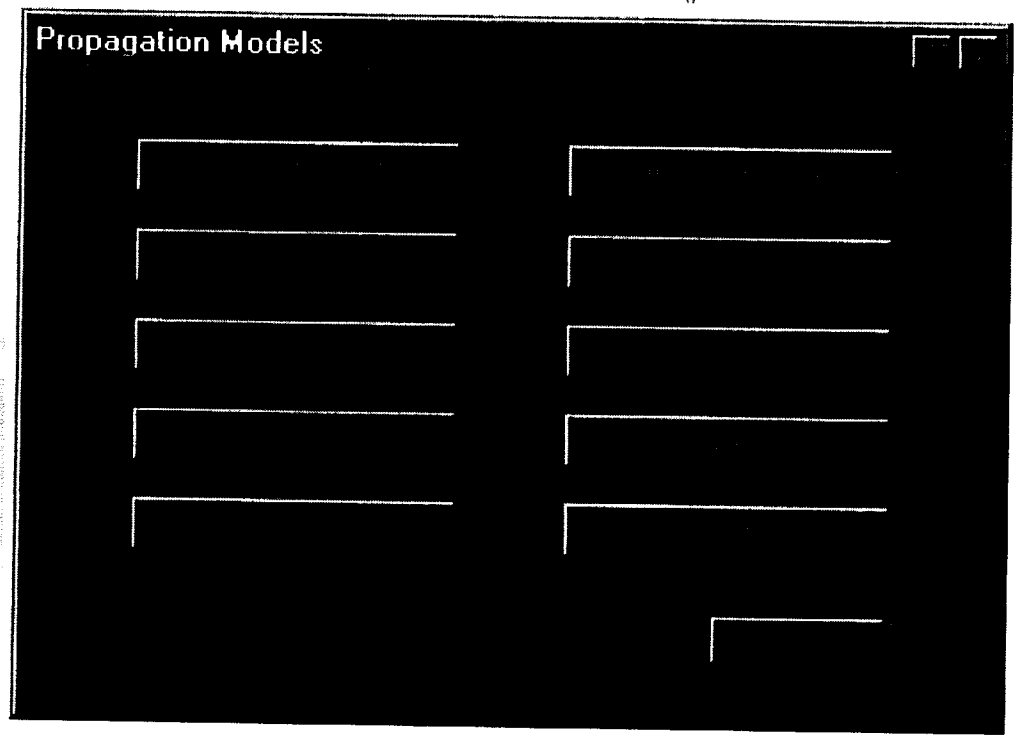
PROPAGATION MODELS DATABASE



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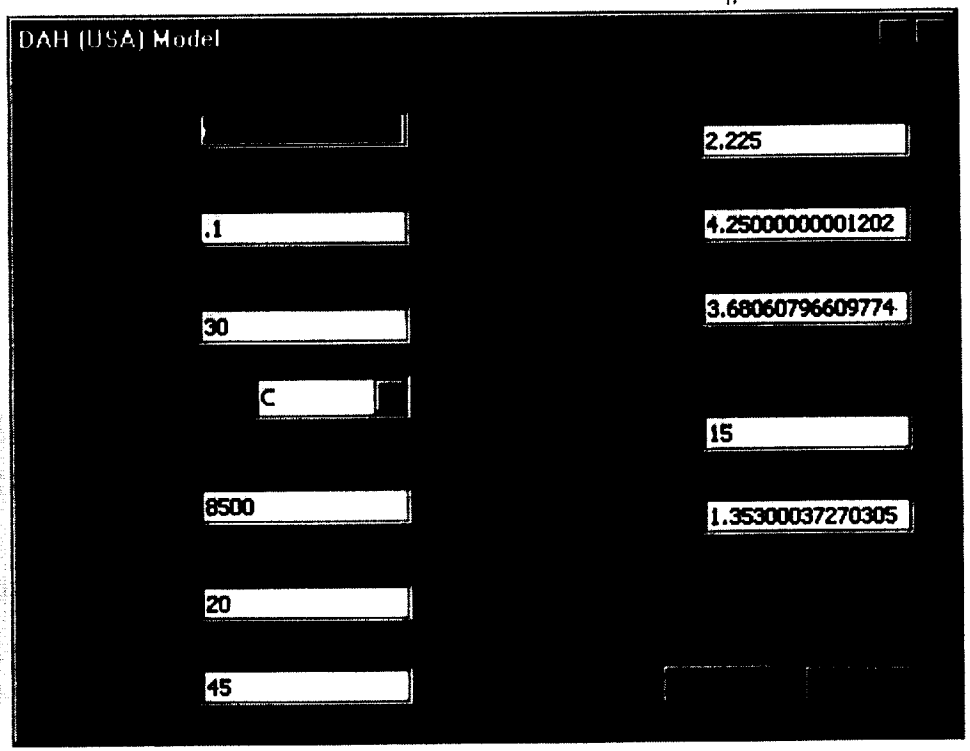

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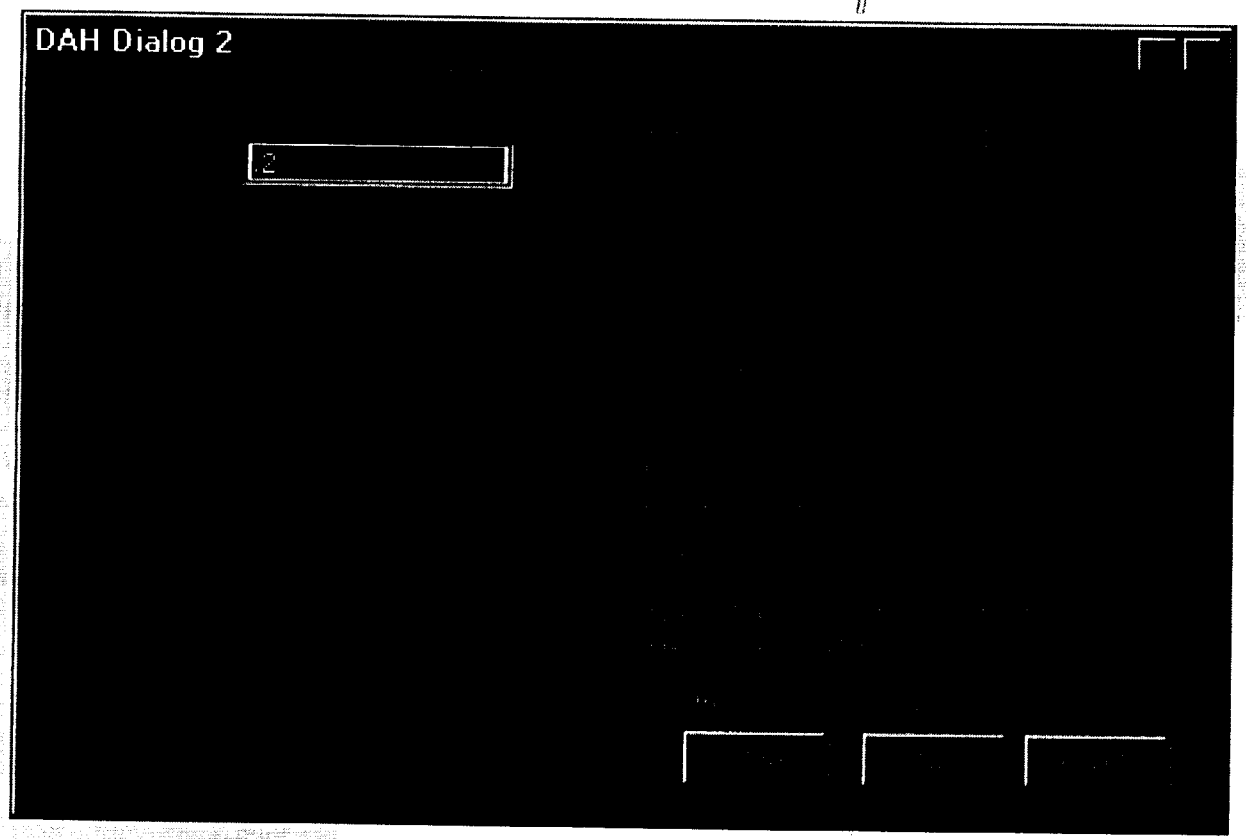

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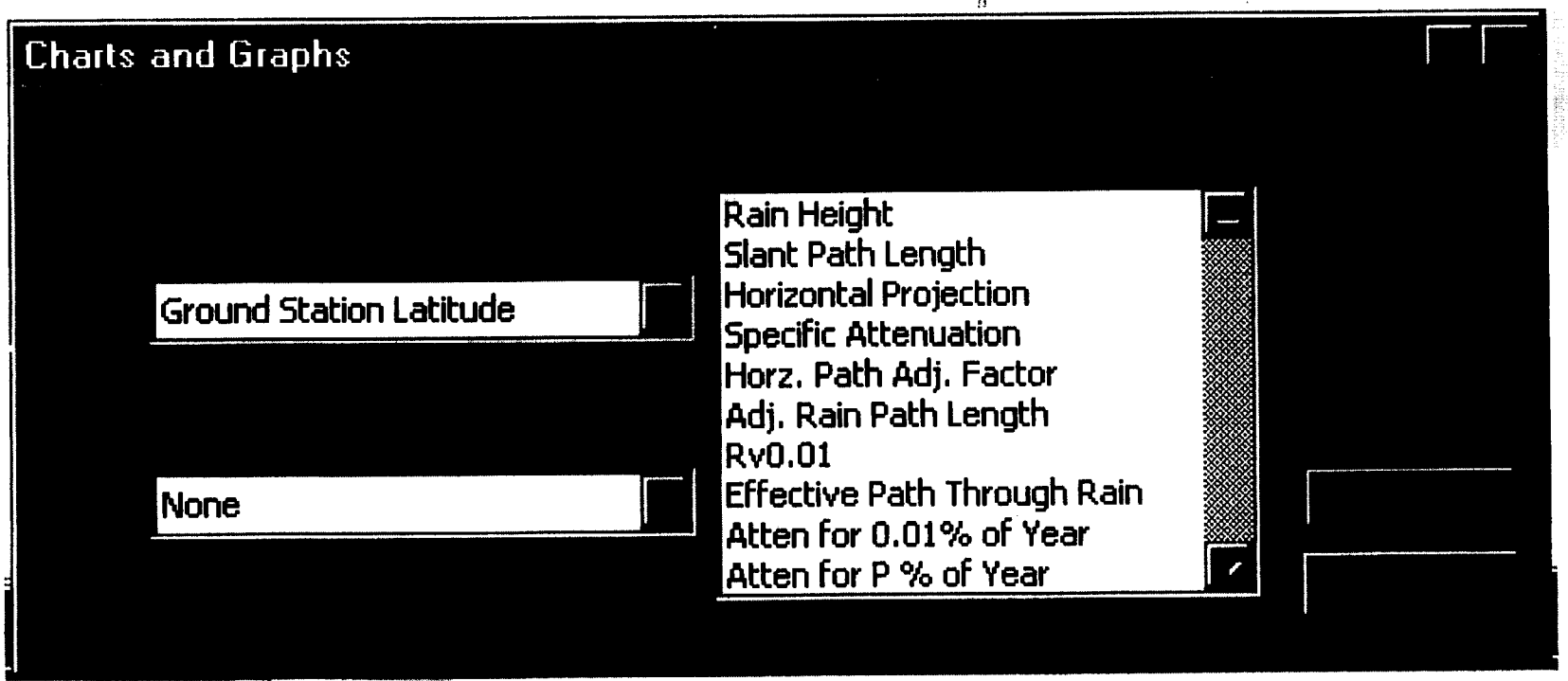

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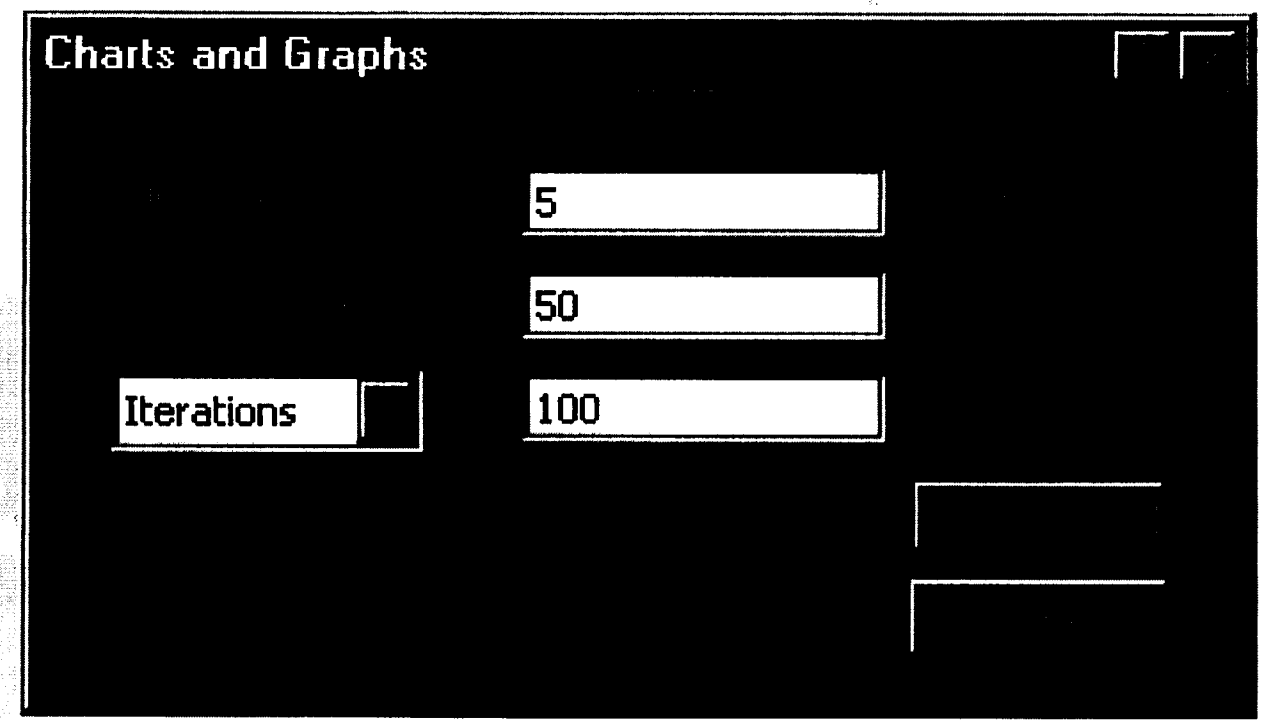

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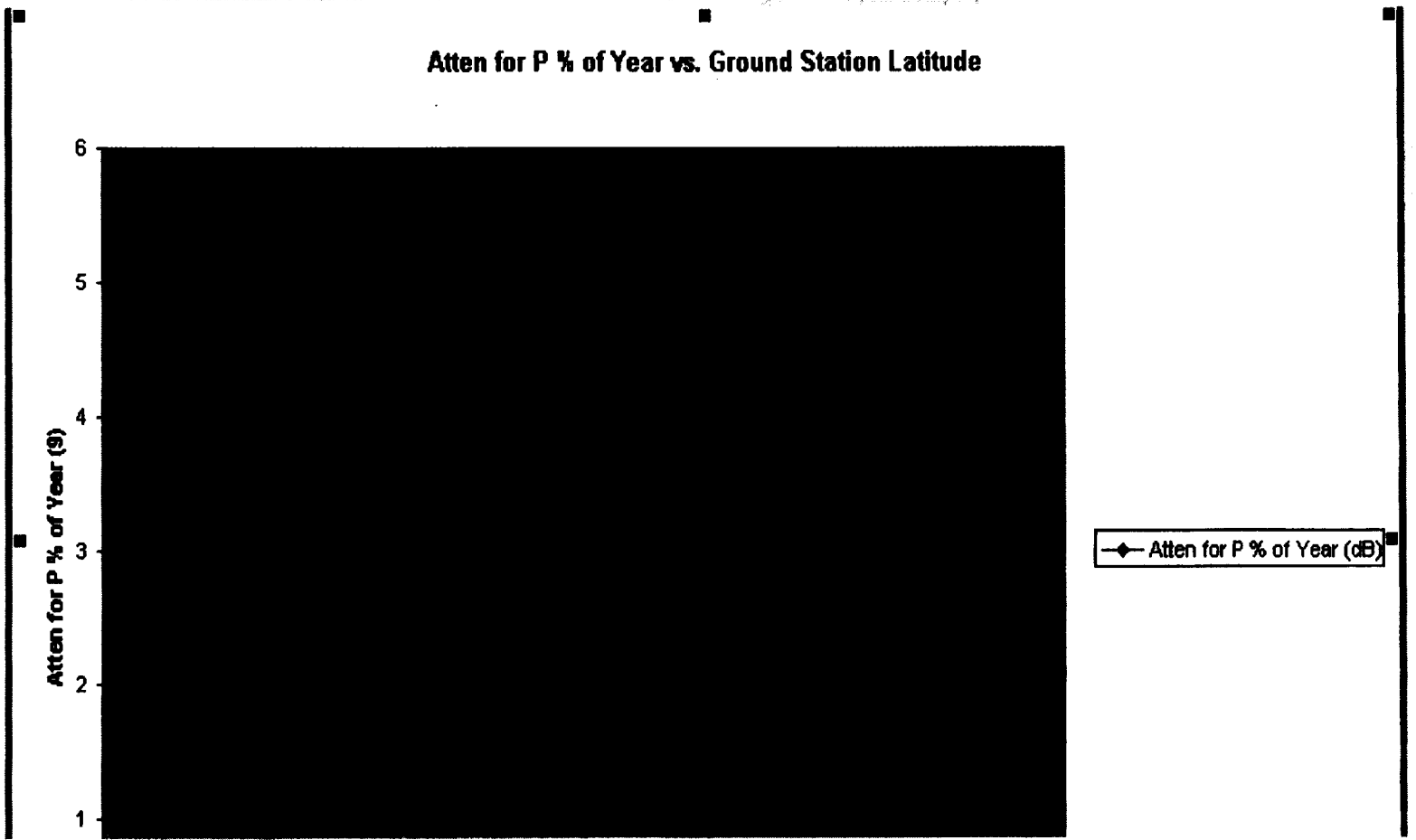
PROPAGATION MODELS DATABASE



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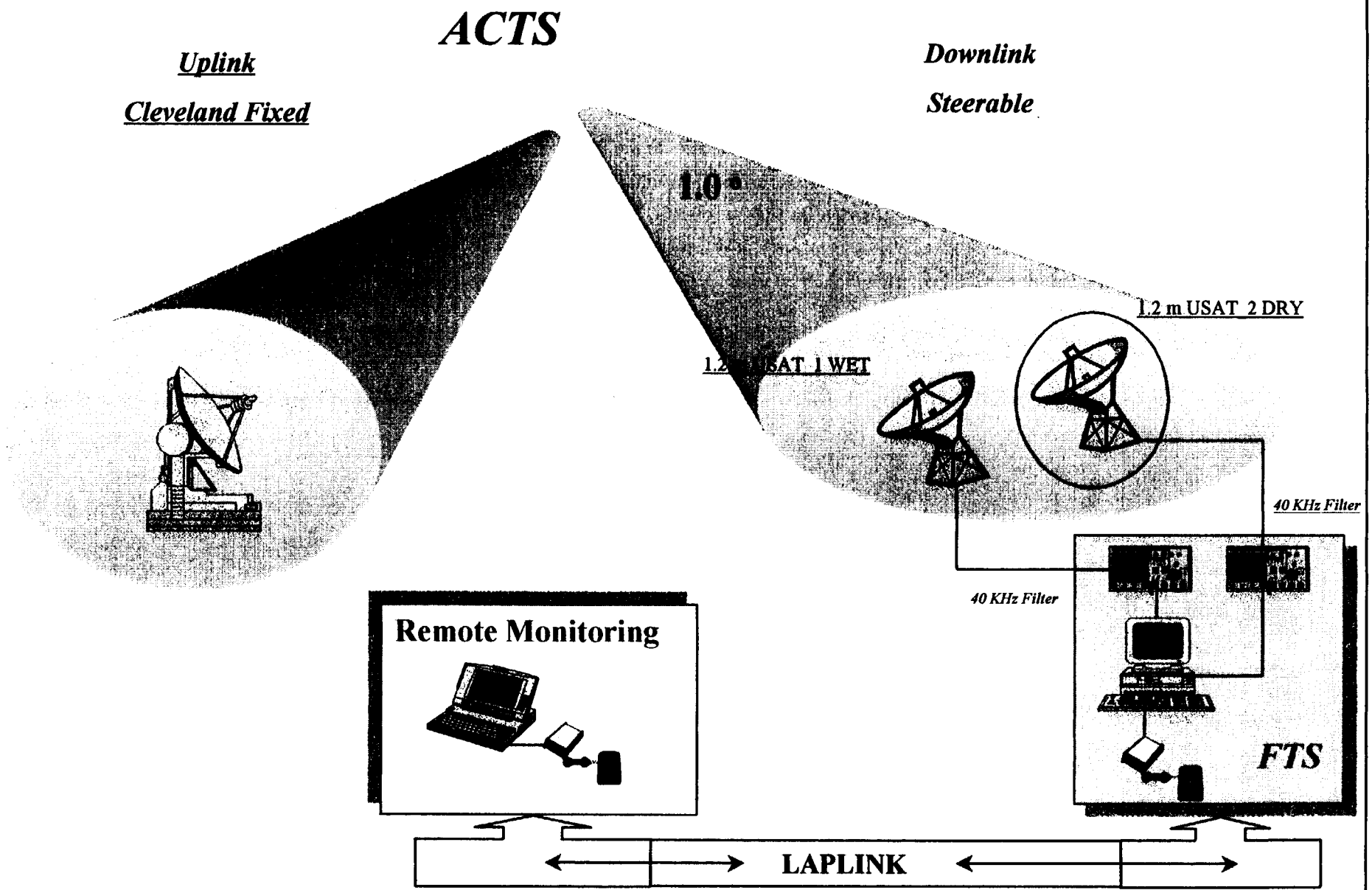
WET ANTENNA STUDIES
NASA LeRC

By: R. Acosta

SUMMARY OF PRESENTATION

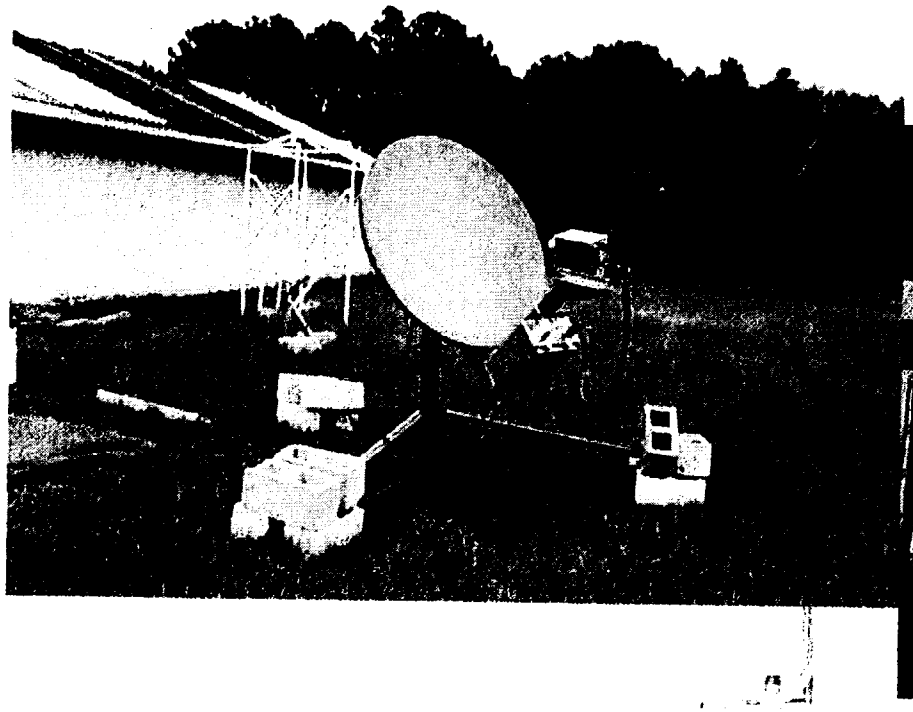
- **EXPERIMENT OVERVIEW**
- **EXPERIMENTAL RESULTS**
- **THEORY vs. EXPERIMENT**
- **CONCLUSIVE REMARKS**

EXPERIMENT OVERVIEW



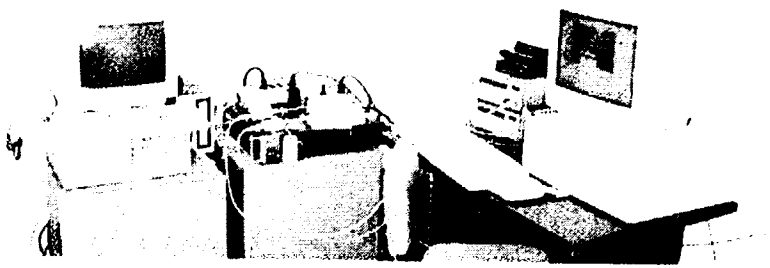
EXPERIMENT OVERVIEW

Wet Reflector



Dry Reflector

Data Acquisition Set-up



ANTENNA WETTING FACTOR - EXPERIMENT

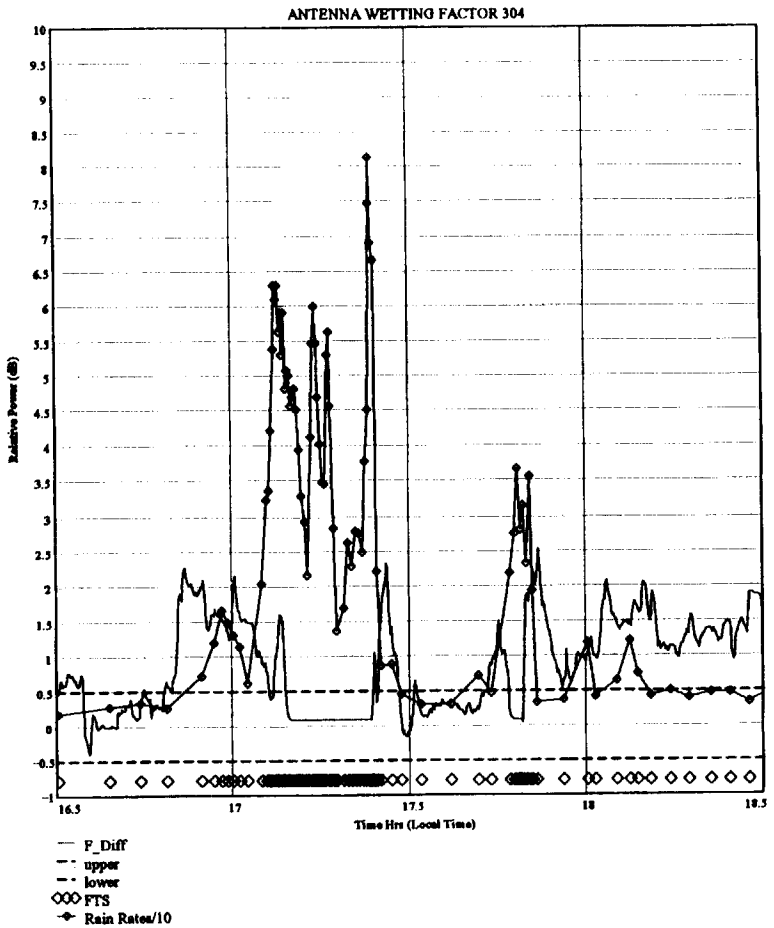


Fig. 1 - Rain Event 304

ANTENNA WETTING FACTOR - EXPERIMENT

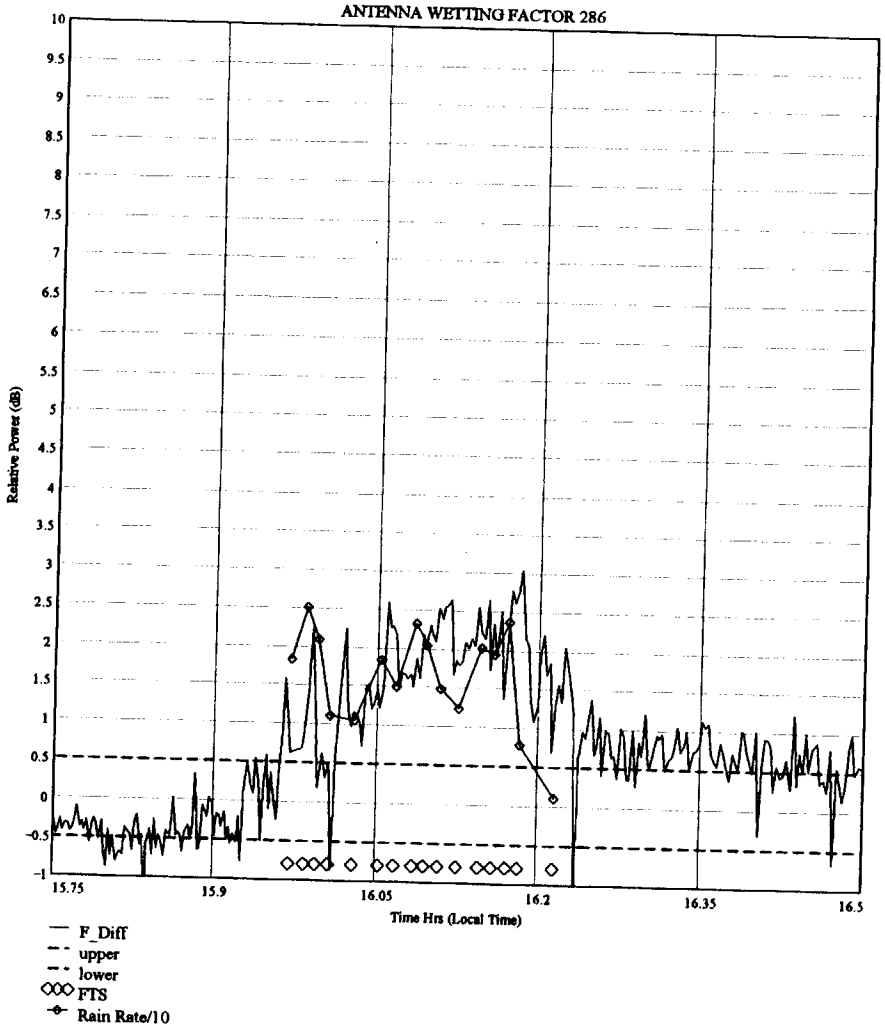


Fig. 2 - Rain Event 286

ANTENNA WETTING FACTOR - EXPERIMENT

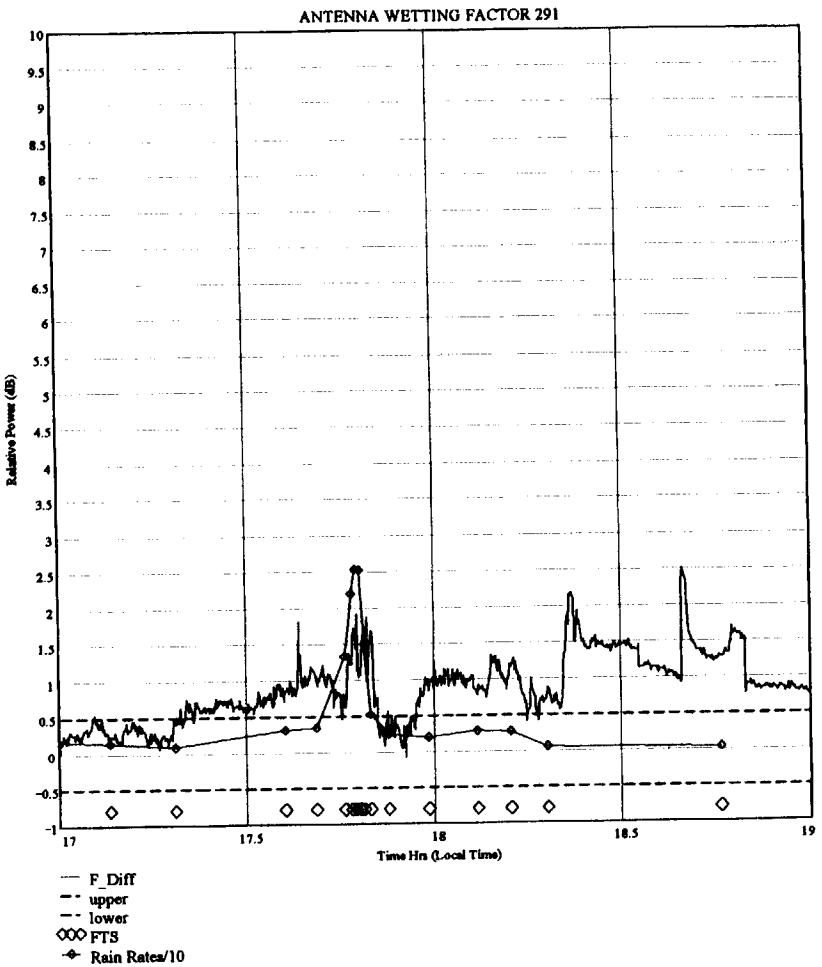


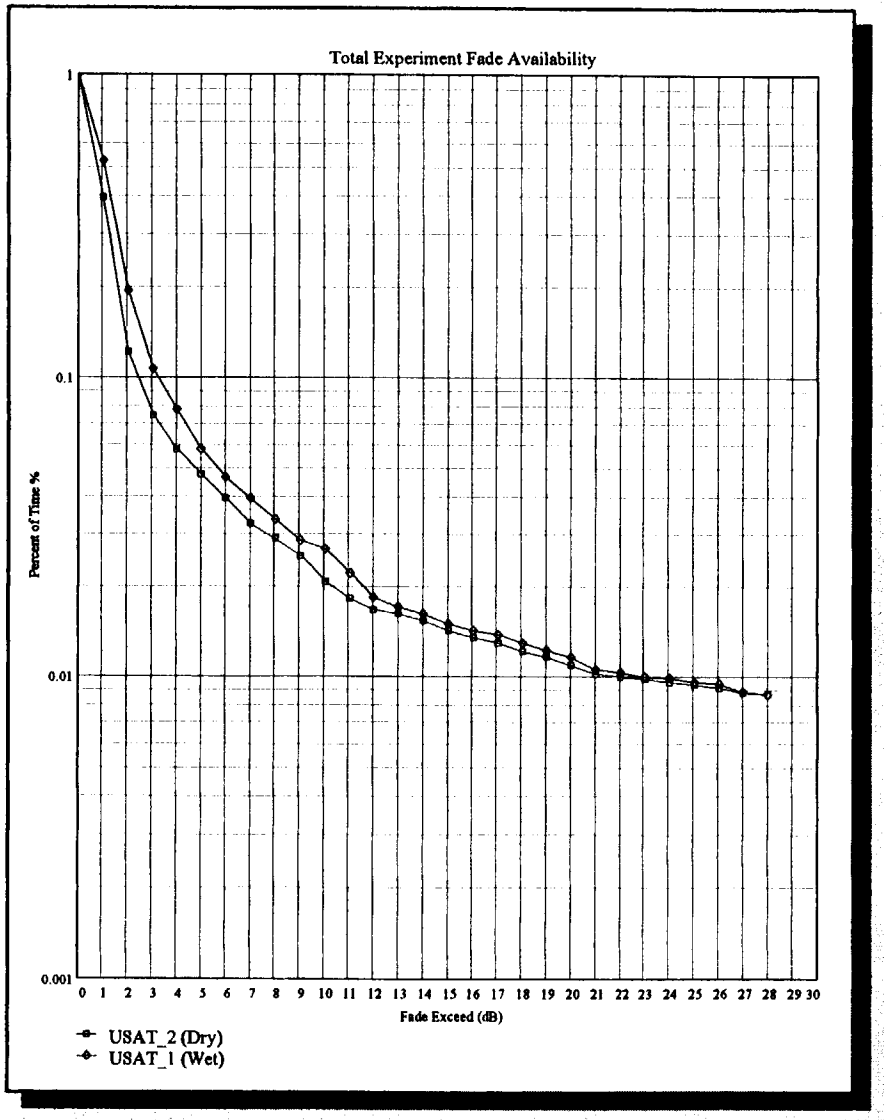
Fig. 3 - Rain Event 291

Wet Antenna Studies at LeRC

Conclusions

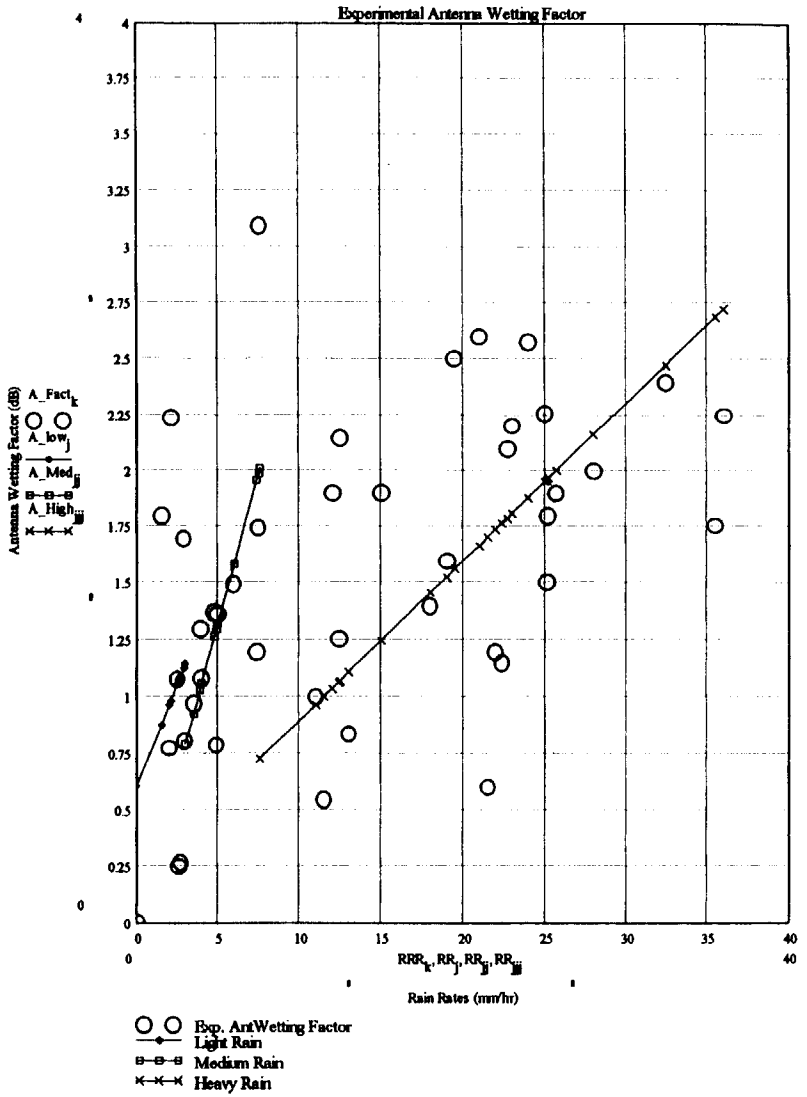
- The antenna wetting factor for the 1.2 m antennas is very similar to the 0.35 m antennas.
- Maximum antenna wetting factor was measured to be between 3 and 4 dB.
- Wet antenna fade availability differed from dry antenna fade availability by 2 dB at lower fades (5-10 dBs)
- Rain shield was not perfect but seemed to work most of time
- Higher antenna wetting factors tend to occur at rain rates of the order of 10 - 40 mm/hr.
- At very high rain rates and high fades both antennas (dry and wet) have a negligible wetness factor.

Experiment Fade Availability



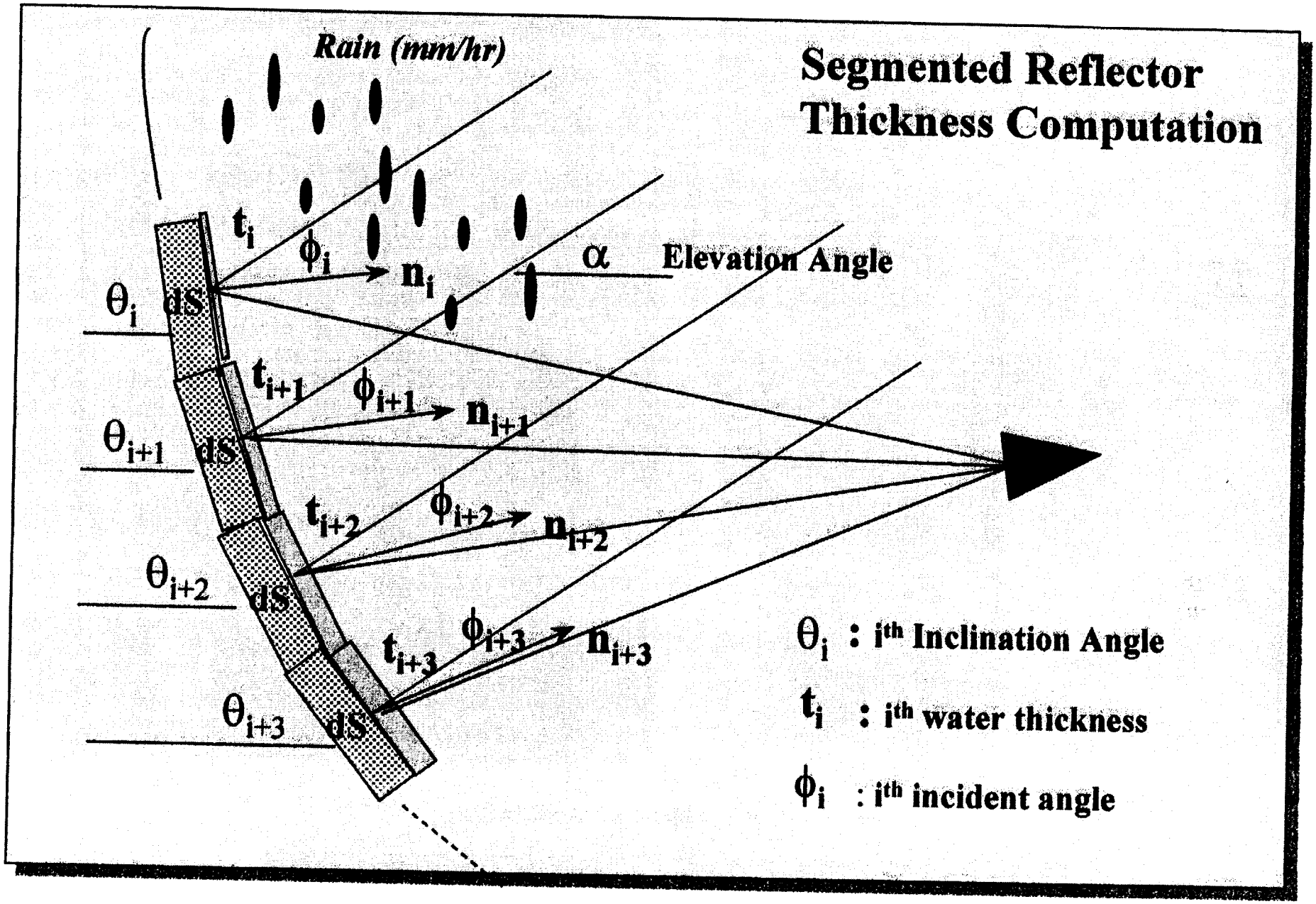
ANTENNA WETTING EXPERIMENT

EXPERIMENTAL SET-UP



EXPERIMENTAL RESULTS

Theoretical Model- WET REFLECTOR

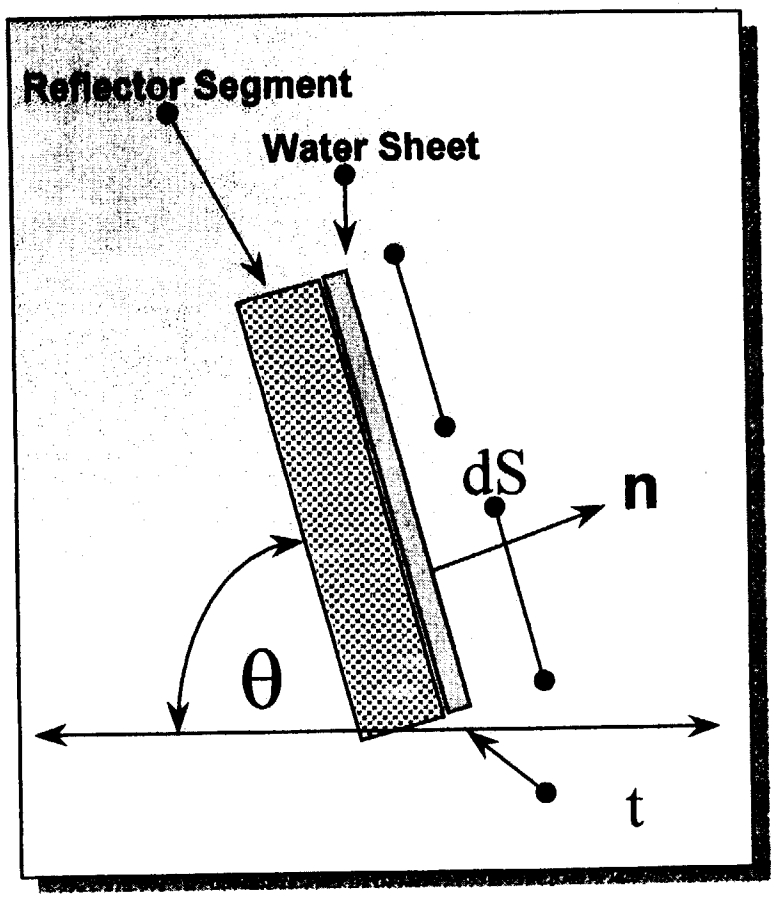


Theoretical Model - WET REFLECTOR

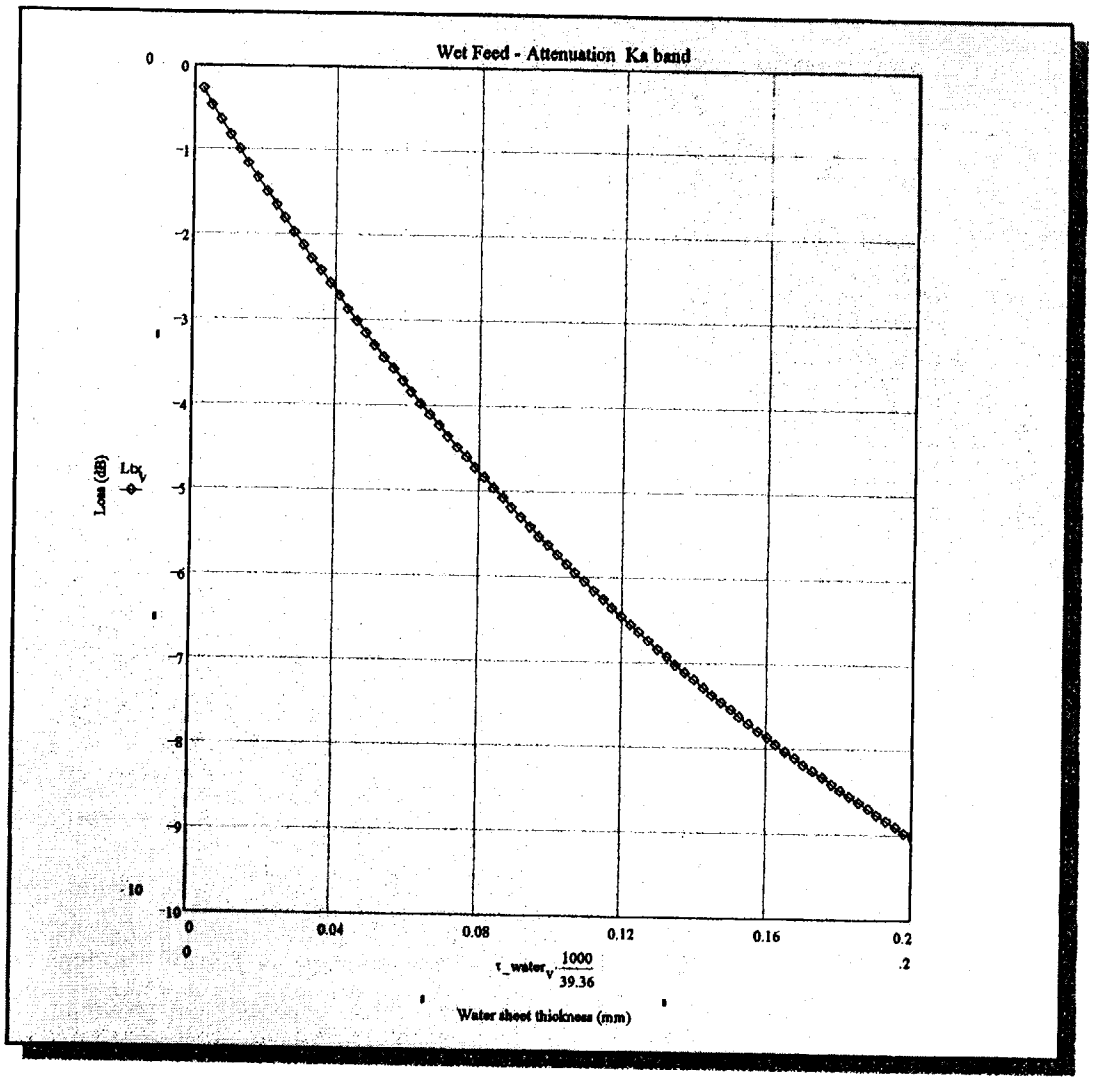
Thickness of water sheet

$$\tau = \sqrt[3]{\frac{3\,\Gamma\,\mu}{\rho\,g\,\sin\theta}}$$

θ: Inclination angle
Γ: Rain rate
μ: Viscosity of water
ρ: Density of water
g : Gravity
ds : Differential length
τ : Average water thickness

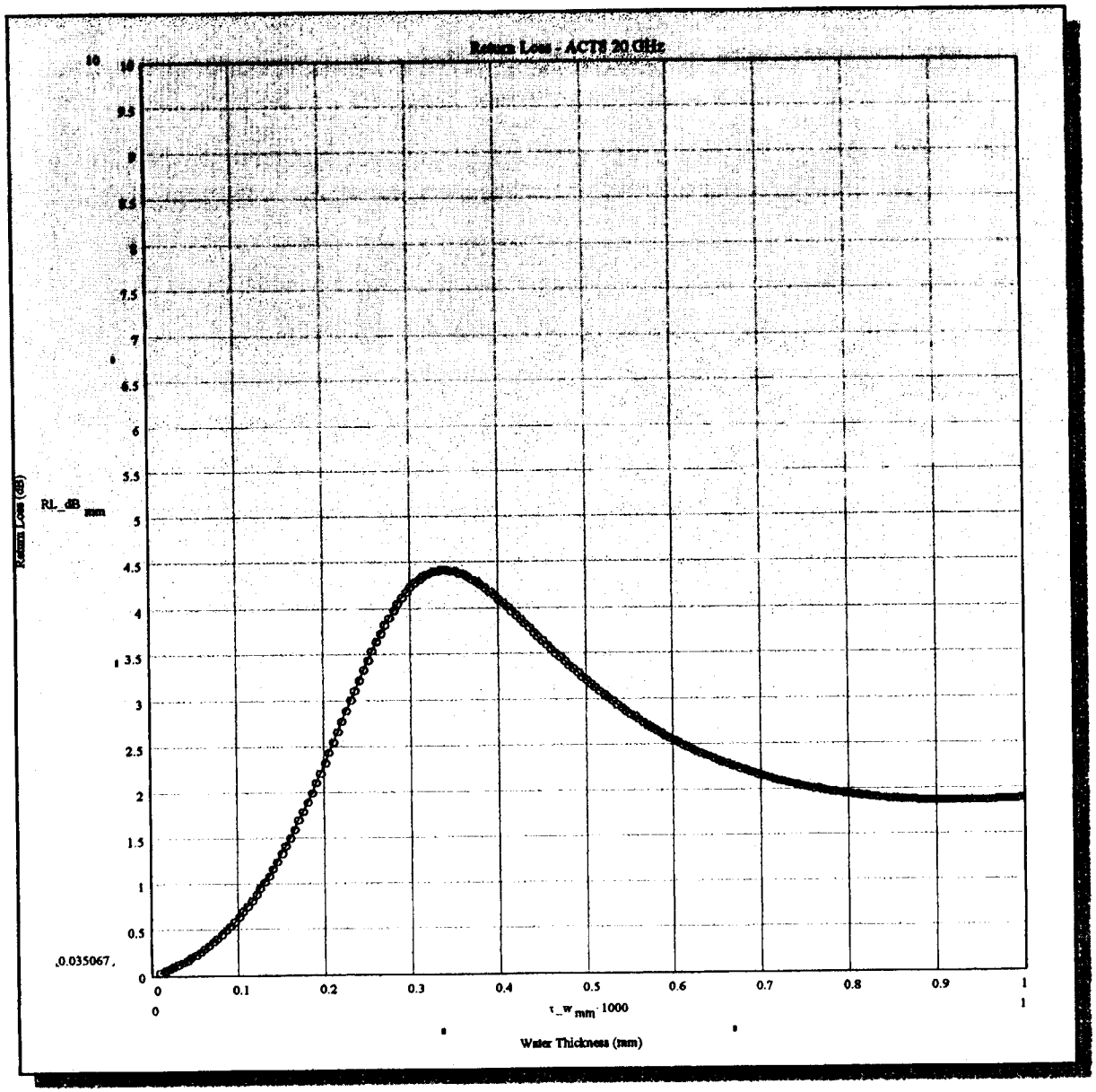


WET FEED ANTENNA- RESULTS

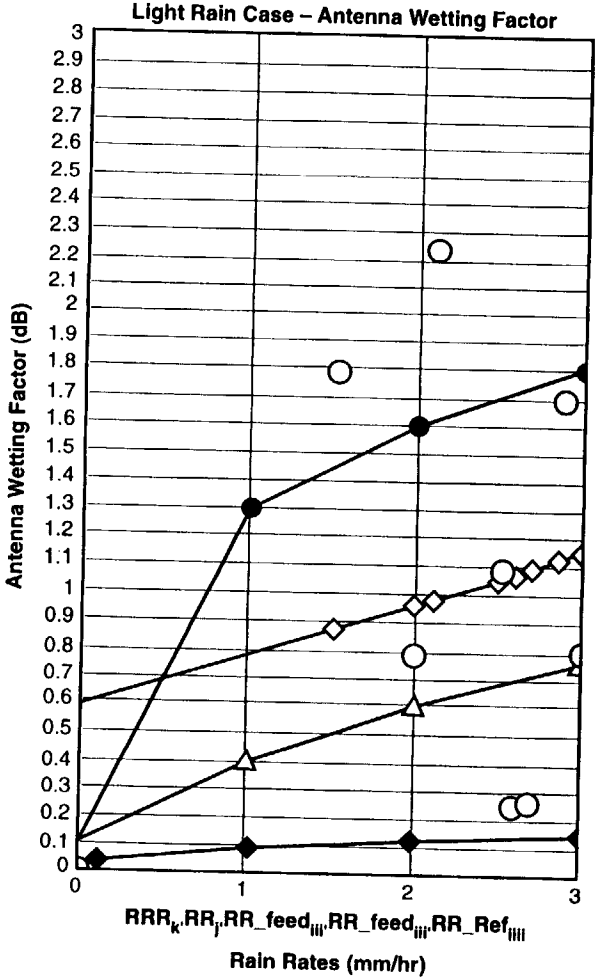


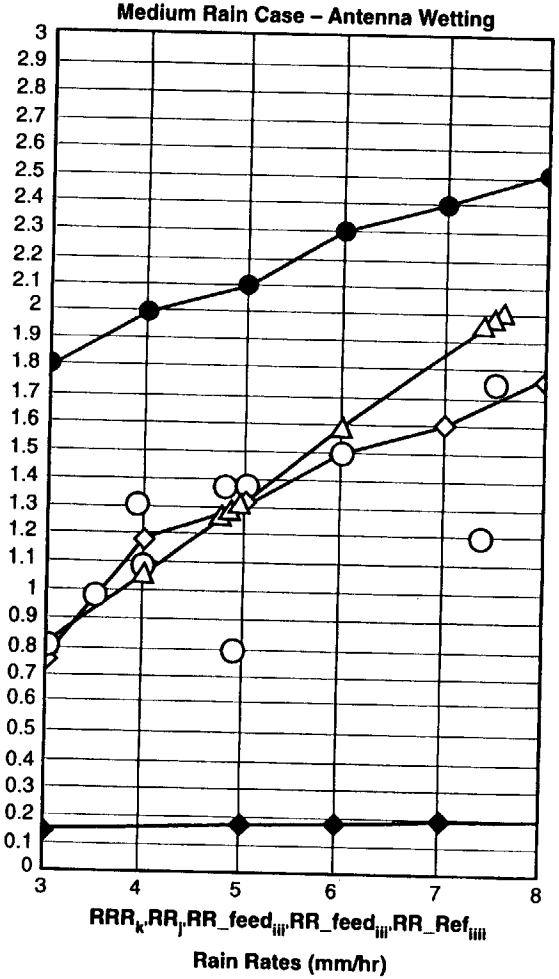
Transmission Line Model - signal loss vs effective water thicknes

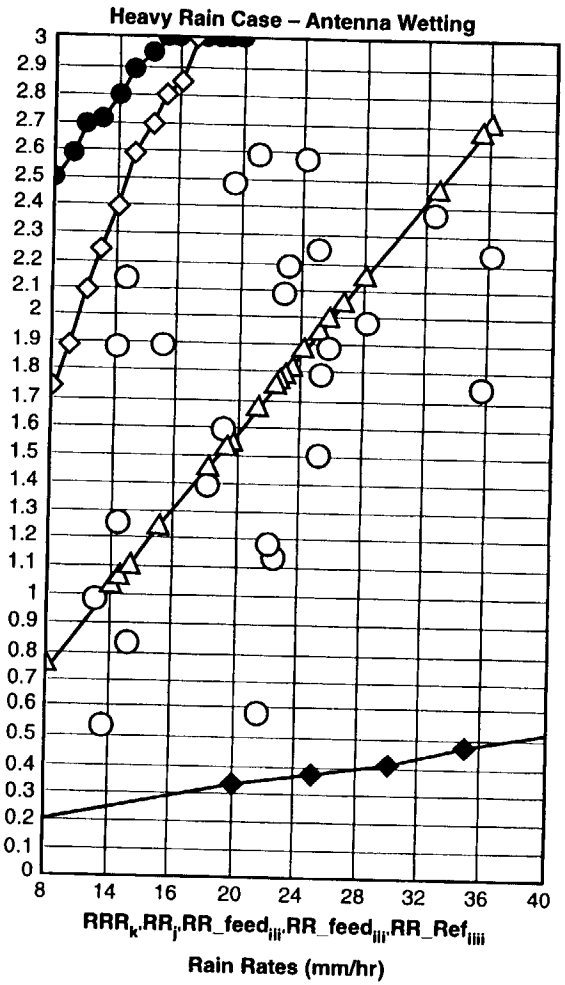
WET REFLECTOR MODEL - Results

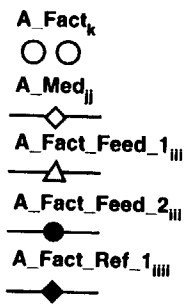


THEORY vs. EXPERIMENT









Wet Antenna Studies at LeRC

Conclusive Remarks

- *The antenna wetting factor for the 1.2 m antennas is very similar to the 0.35 m antennas.*
- *Maximum antenna wetting factor was measured to be between 3 and 4 d and it was limited by dynamic range of the system.*
- *Wet antenna fade availability differed from dry antenna fade availability by 2 dB at lower fades (5-10 dBs)*
- *Rain shield was not perfect but seemed to work most of time*
- *Higher antenna wetting factors tend to occur at rain rates of the order of 10 - 40 mm/hr but it may be limited to dynamic range of system.*
- *Antenna wetting factor is a random variable.*
- *Future work will include feed compensation and statistical data.*

Use of a Software Simulator for Modeling the ACTS Link

Roy Laurens
Parag Manihar
Ioannis Pavlidis
Satish Shetty

ACTS Propagation Workshop
Oklahoma City, OK
October 22-23, 1998

Information Networking Institute
Carnegie Mellon University

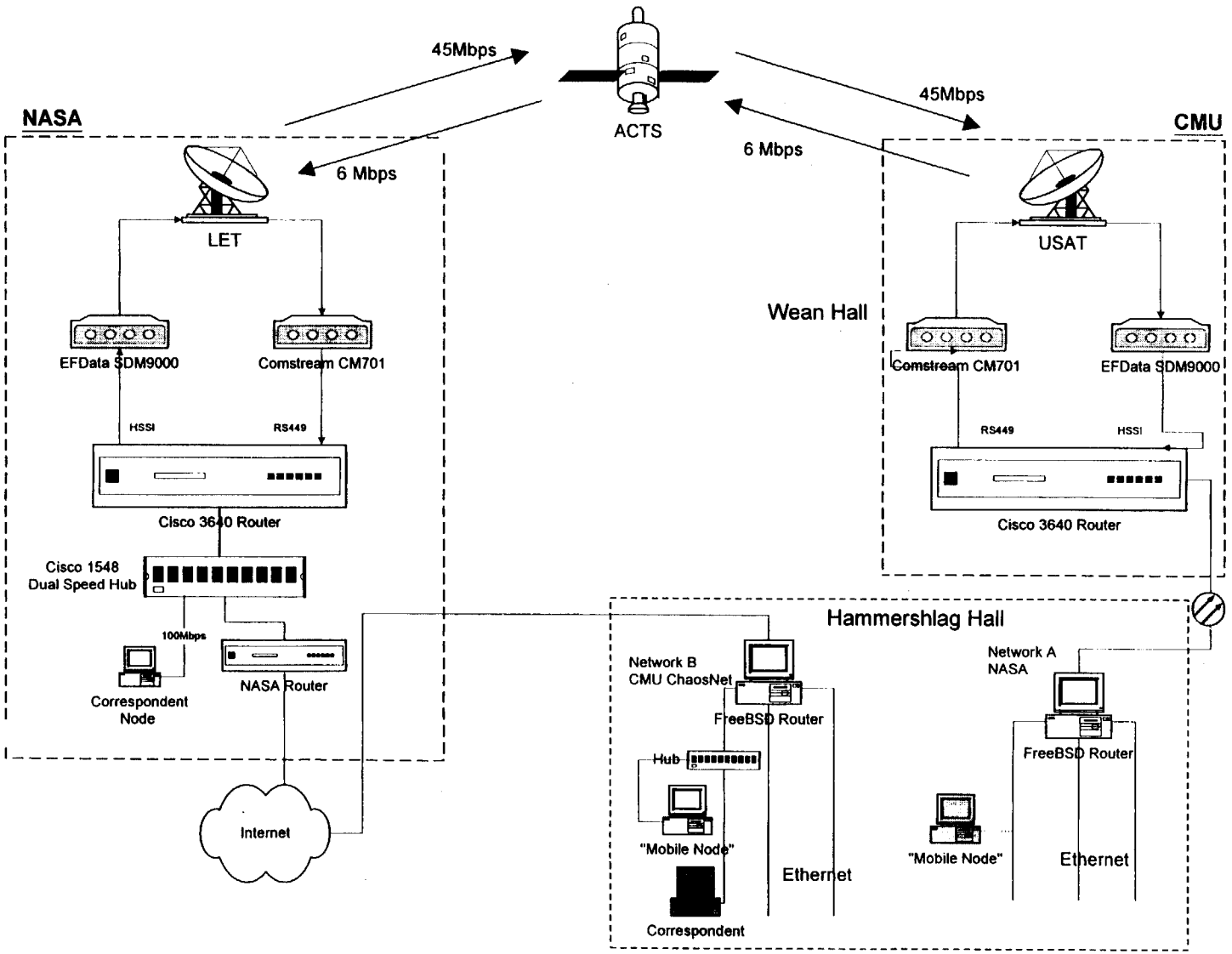
Agenda

- CMU/NASA ACTS Experiment
- Network Simulator (ns)
- Error Modeling for the ACTS Link
- Data collection and analysis
- Conclusions and Future Research

Goals

- *ACTS Error Modeling module for NS*
- **Performance analysis and Improvement of TCP behavior over ACTS**
- **Mobile IP performance over ACTS**

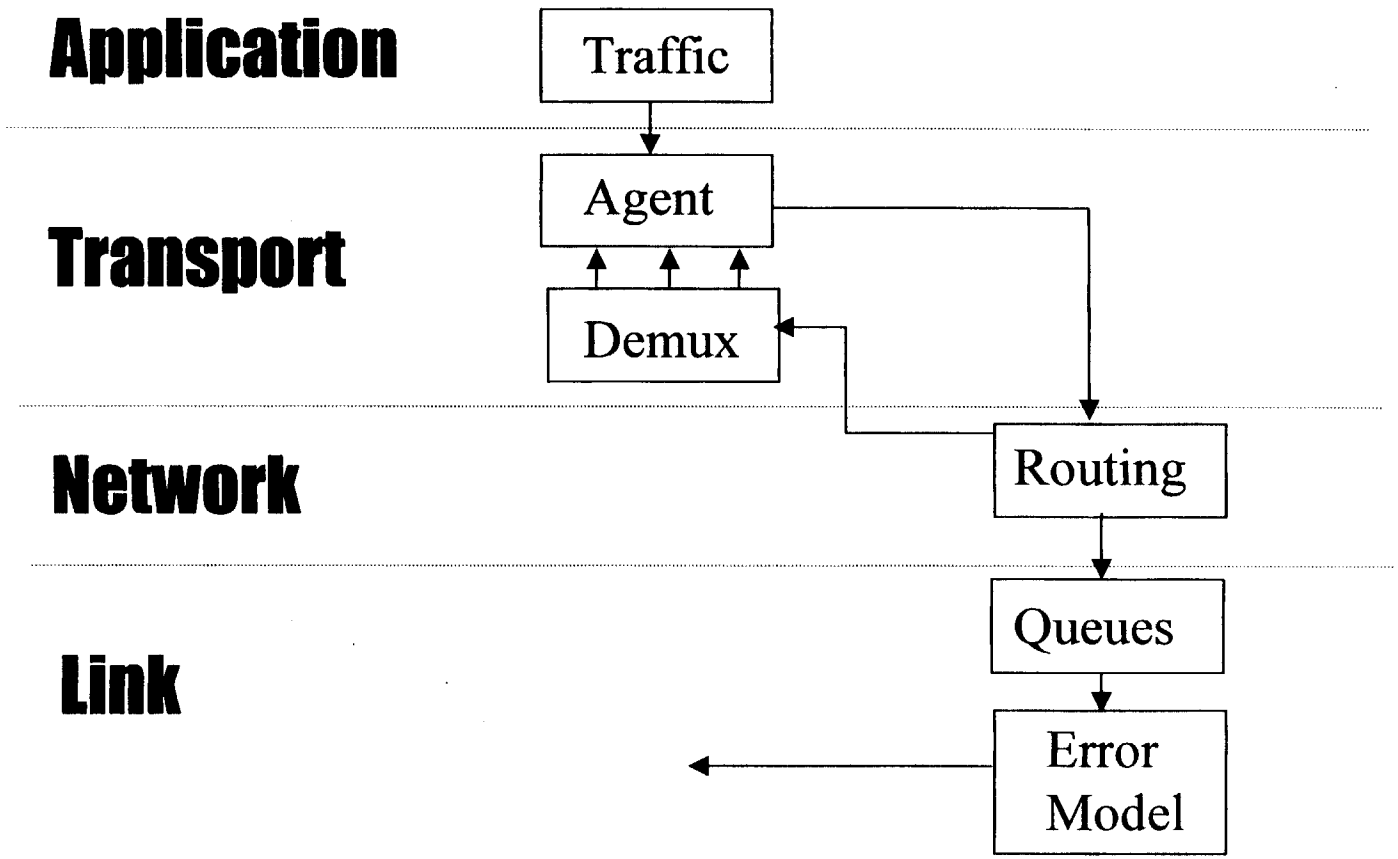
CMU/NASA ACTS Experiment



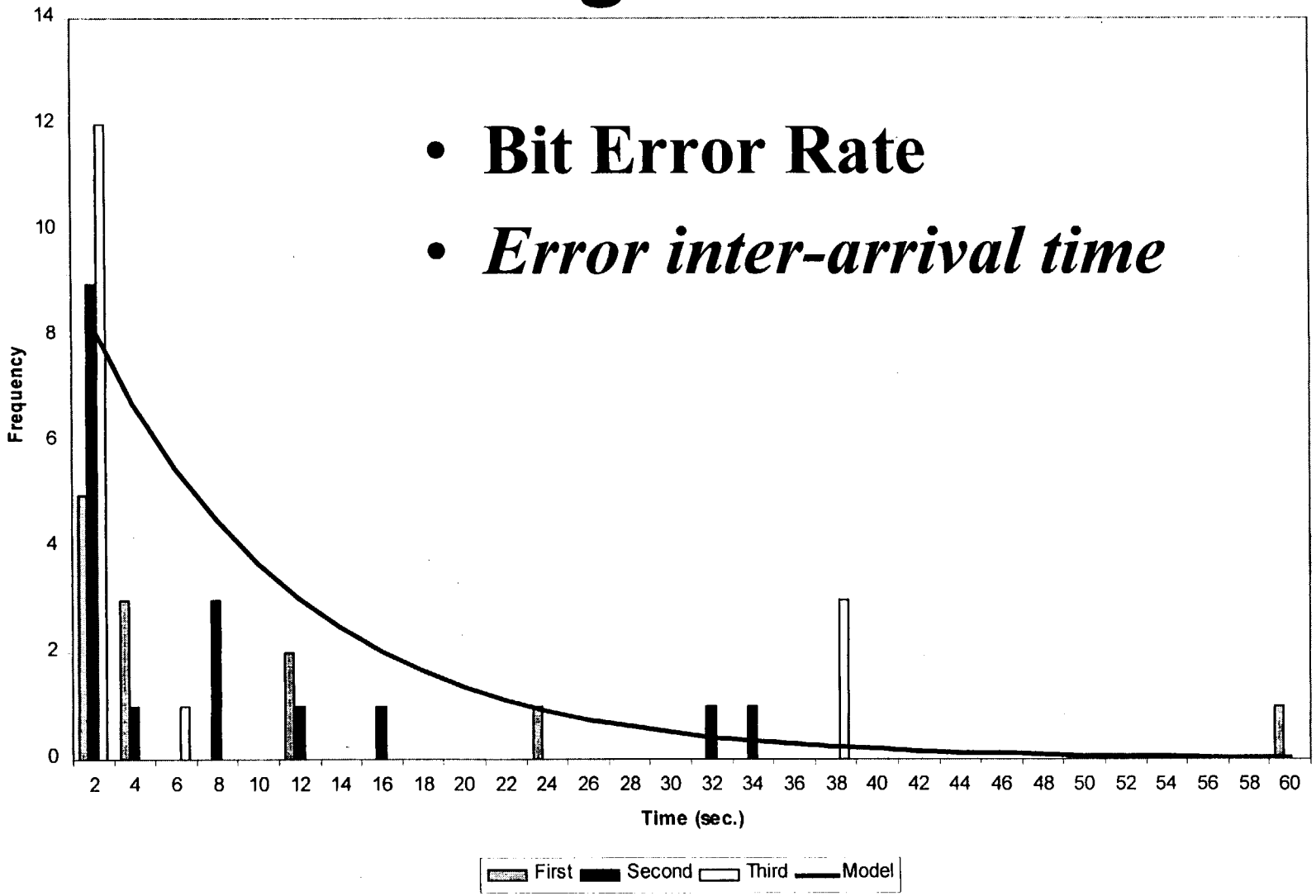
Network Simulator (ns)

- Collaborative effort: USC/ISI, PARC, LBNL & UCB
- Event based queue modeling
- Easily extendable modular framework
- Protocol definition and simulation configuration using scripting language
- Graphical tools for animation and configuration

ns Architecture



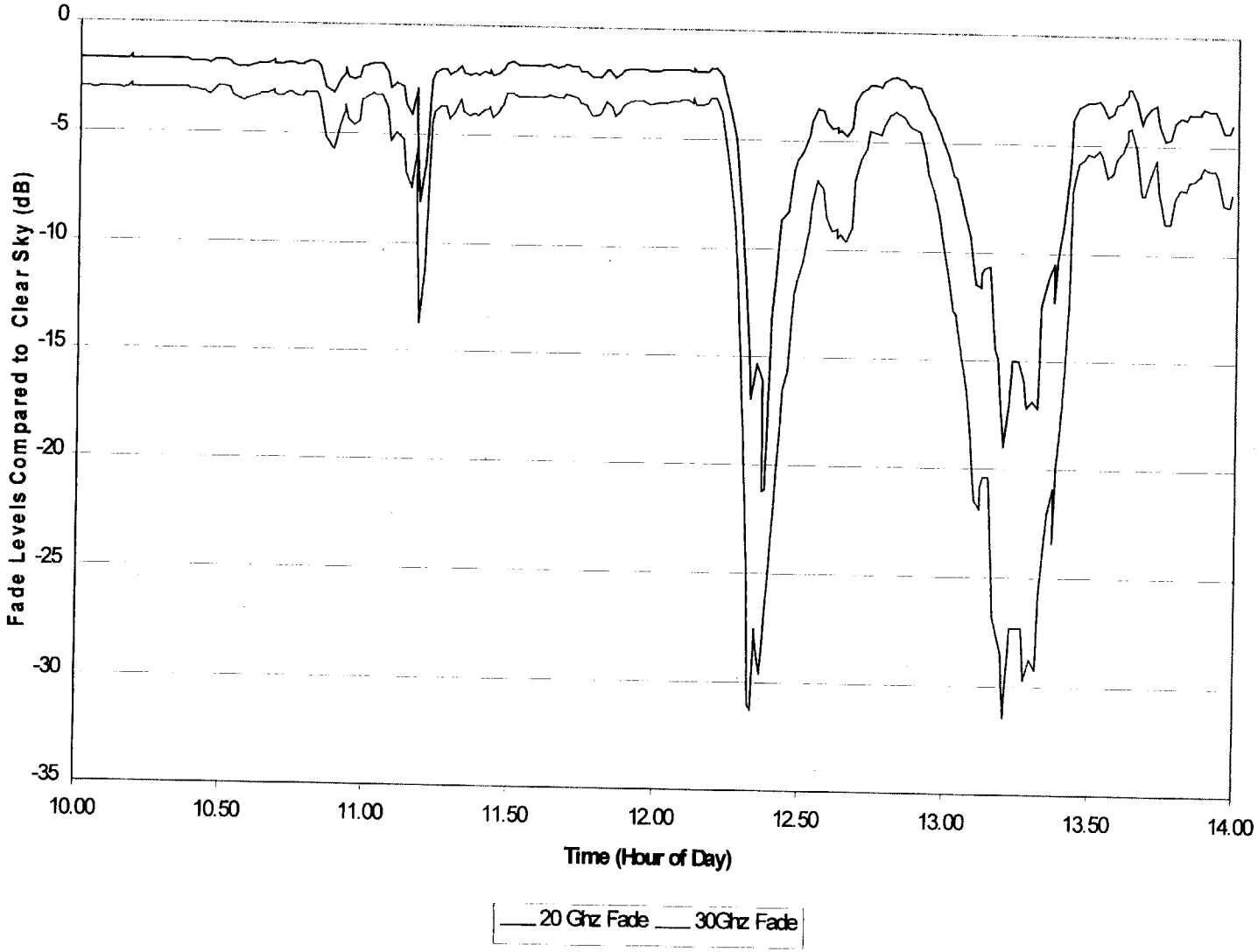
Error modeling in ns



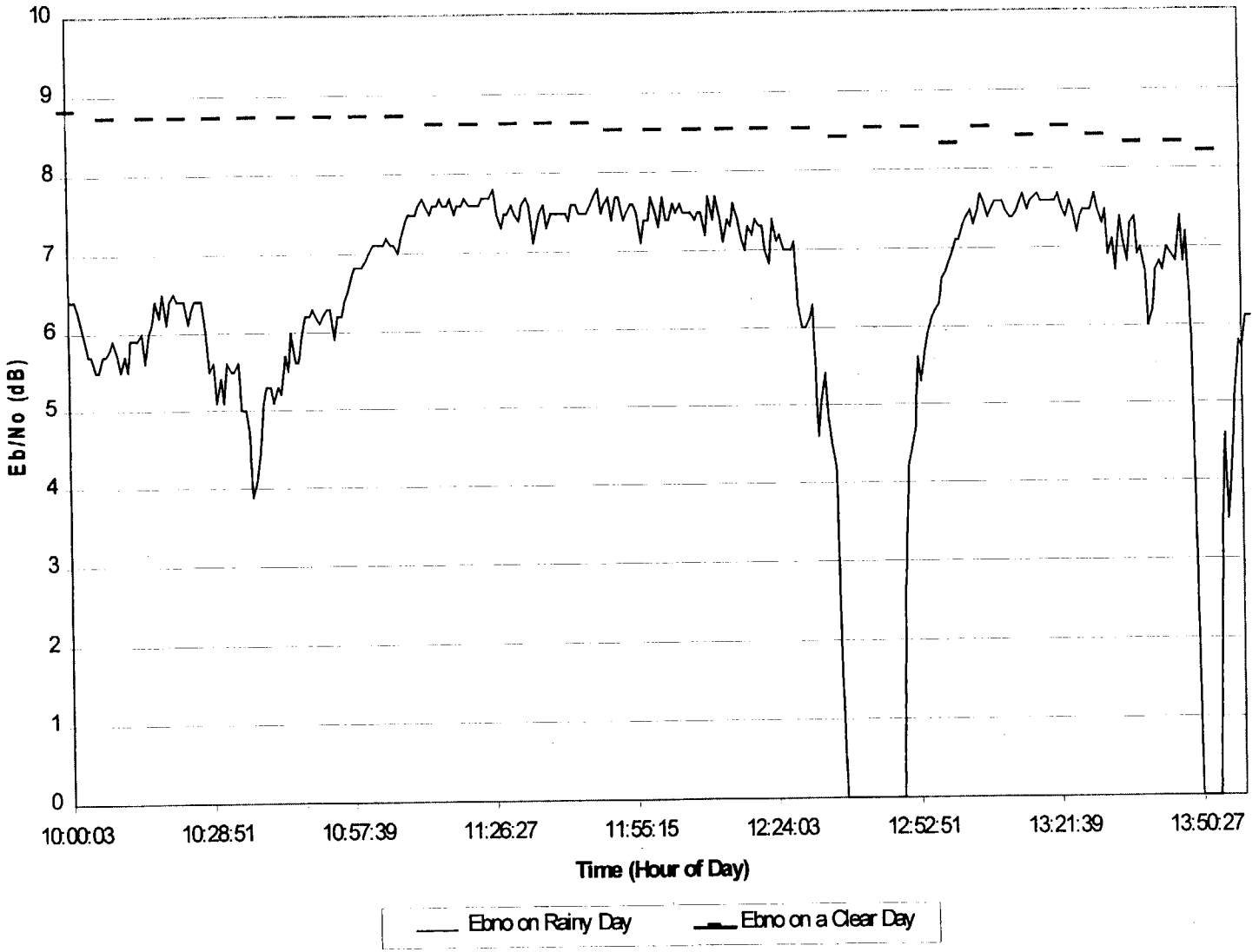
Experiment Data

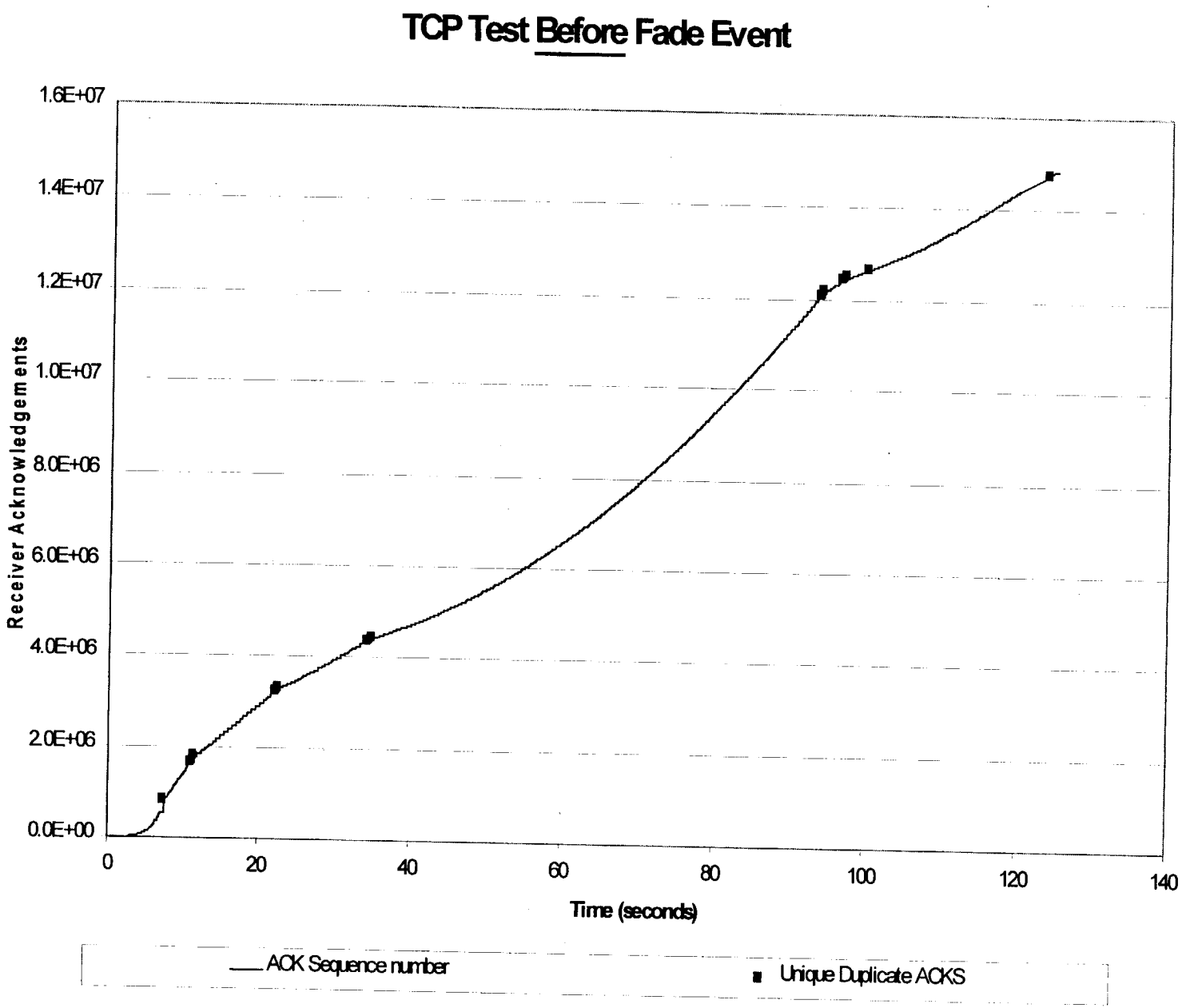
- Eb/No, BER, Beacon Fade and TCP data
- Signal Degradation on a Rainy day
- Effect on the TCP tests performed

Fade data on Rainy Day from Beacon Signals at 20Ghz and 30Ghz

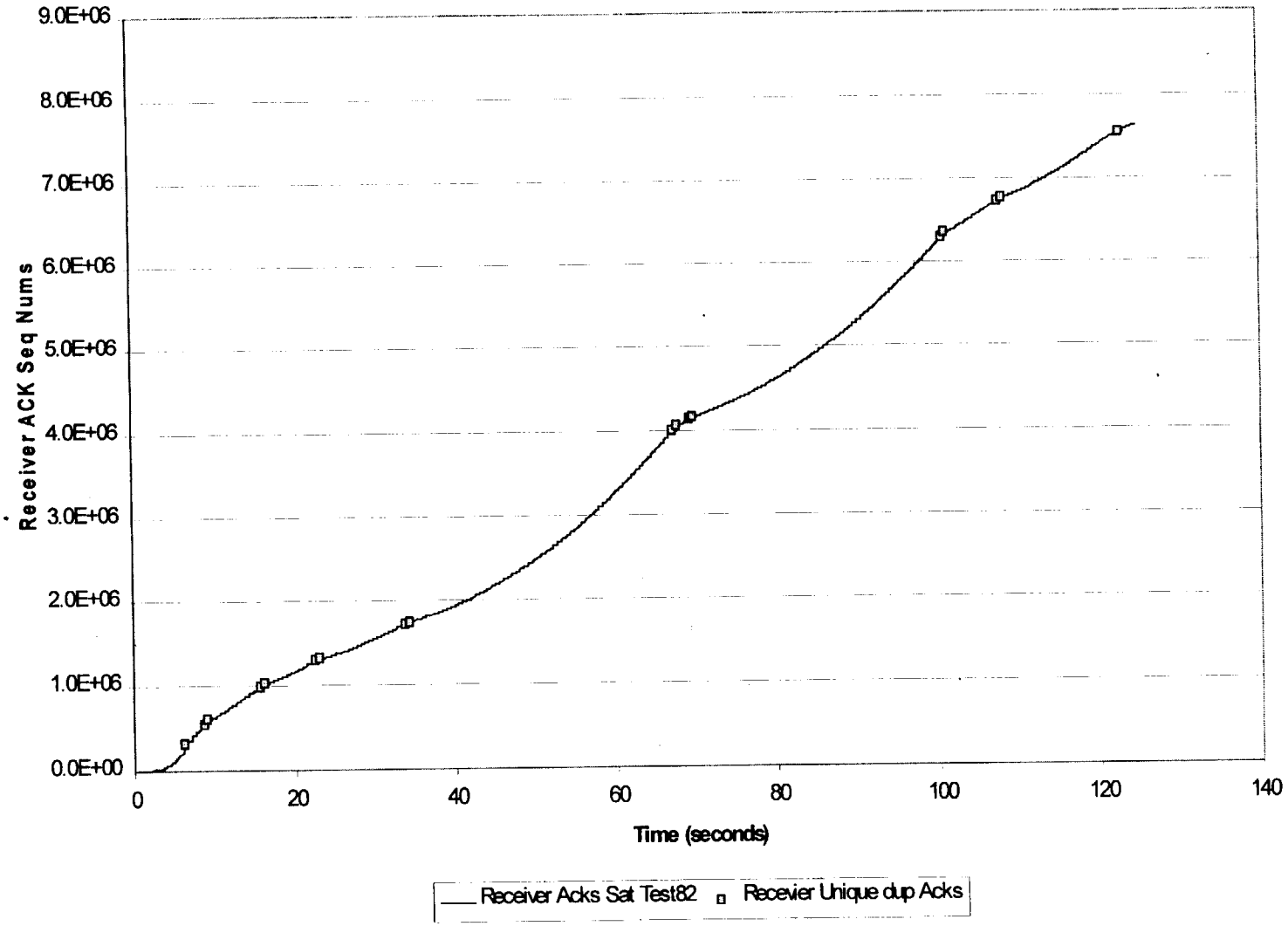


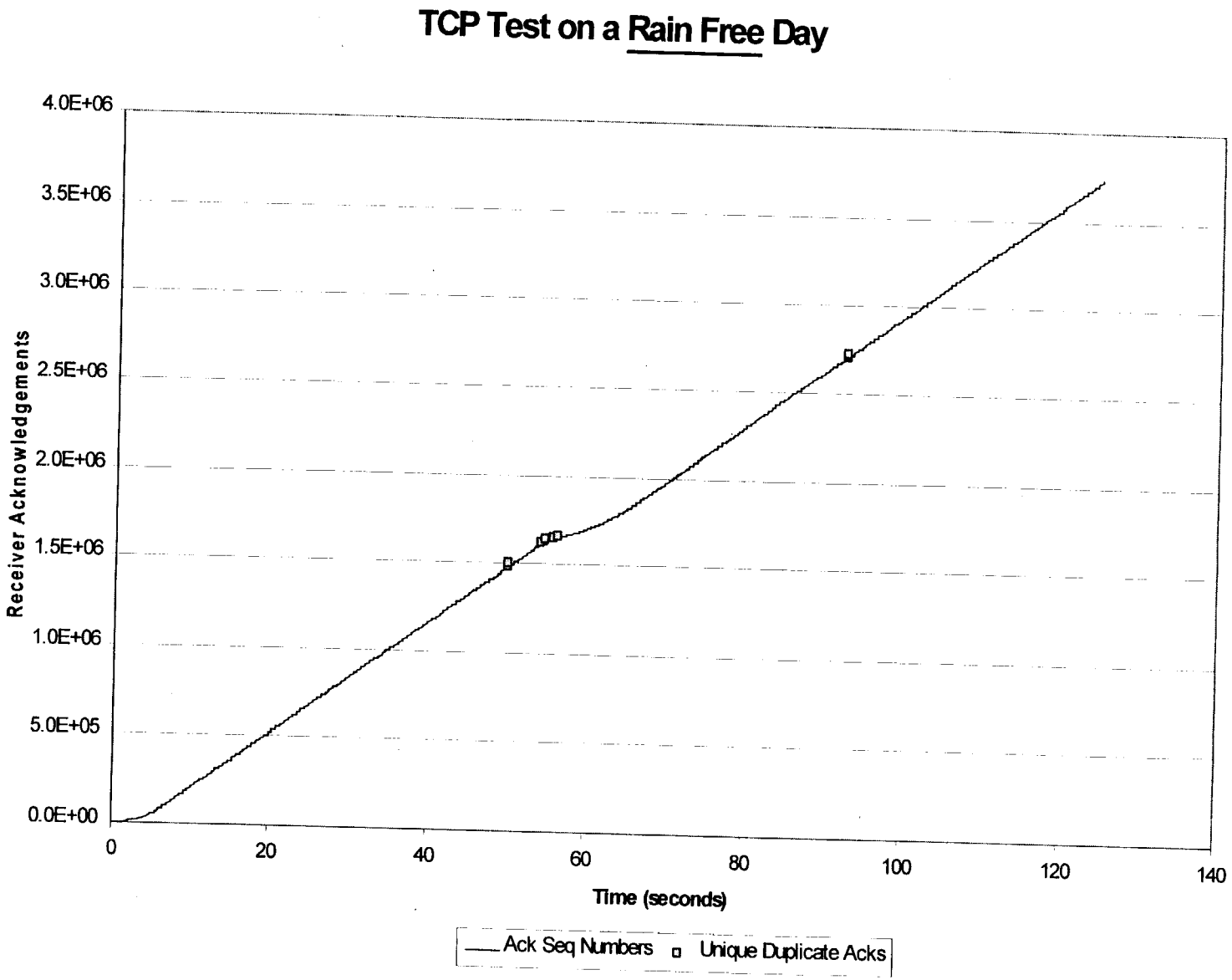
Eb/No plot for the Rainy Day [08/10/98]




TCP Test Before Fade Event
1.6E+07
1.4E+07
1.2E+07
1.0E+07
8.0E+06
6.0E+06
4.0E+06
2.0E+06
0.0E+00
Receiver Acknowledgements
0
20
40
60
80
100
120
140
Time (seconds)
ACK Sequence number
Unique Duplicate ACKS

TCP Test Near Fade Event

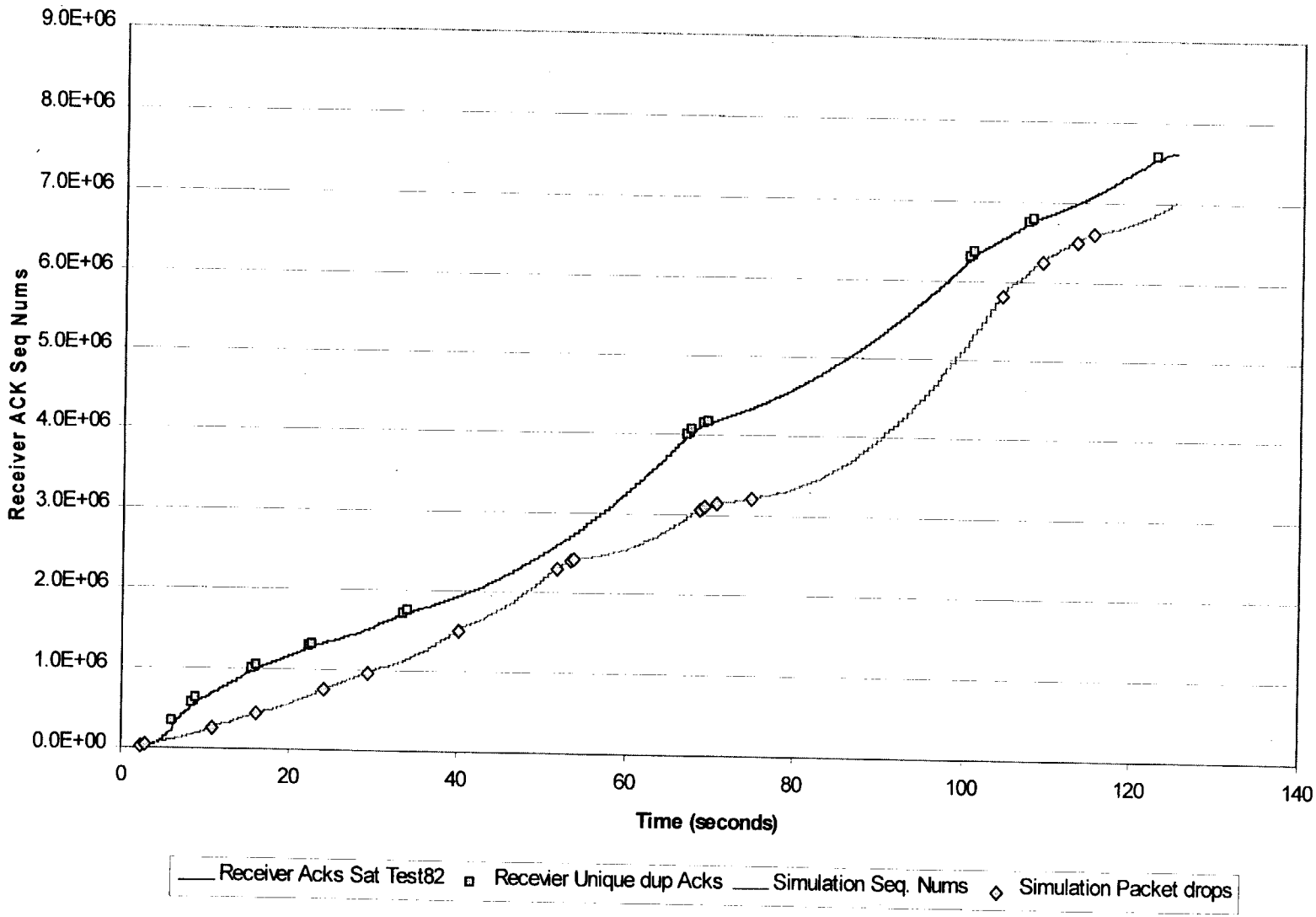



TCP Test on a Rain Free Day
Receiver Acknowledgements
4.0E+06
3.5E+06
3.0E+06
2.5E+06
2.0E+06
1.5E+06
1.0E+06
5.0E+05
0.0E+00
0
20
40
60
80
100
120
140
Time (seconds)
Ack Seq Numbers
Unique Duplicate Acks

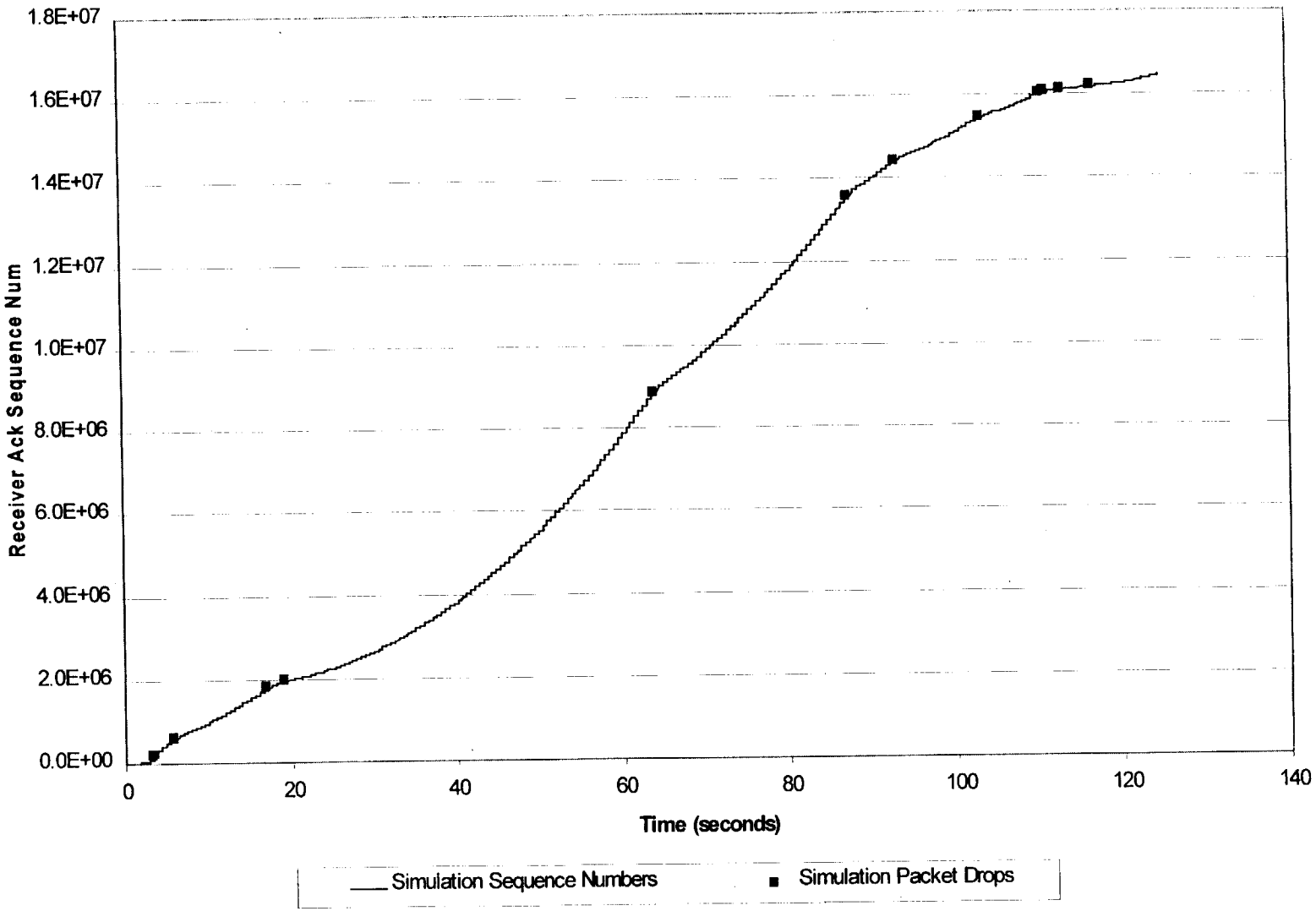
Simulation verification

- Modeling the Observed Link Conditions
- Model vs Observed Link Behavior
- Multiple Simulation Run Results

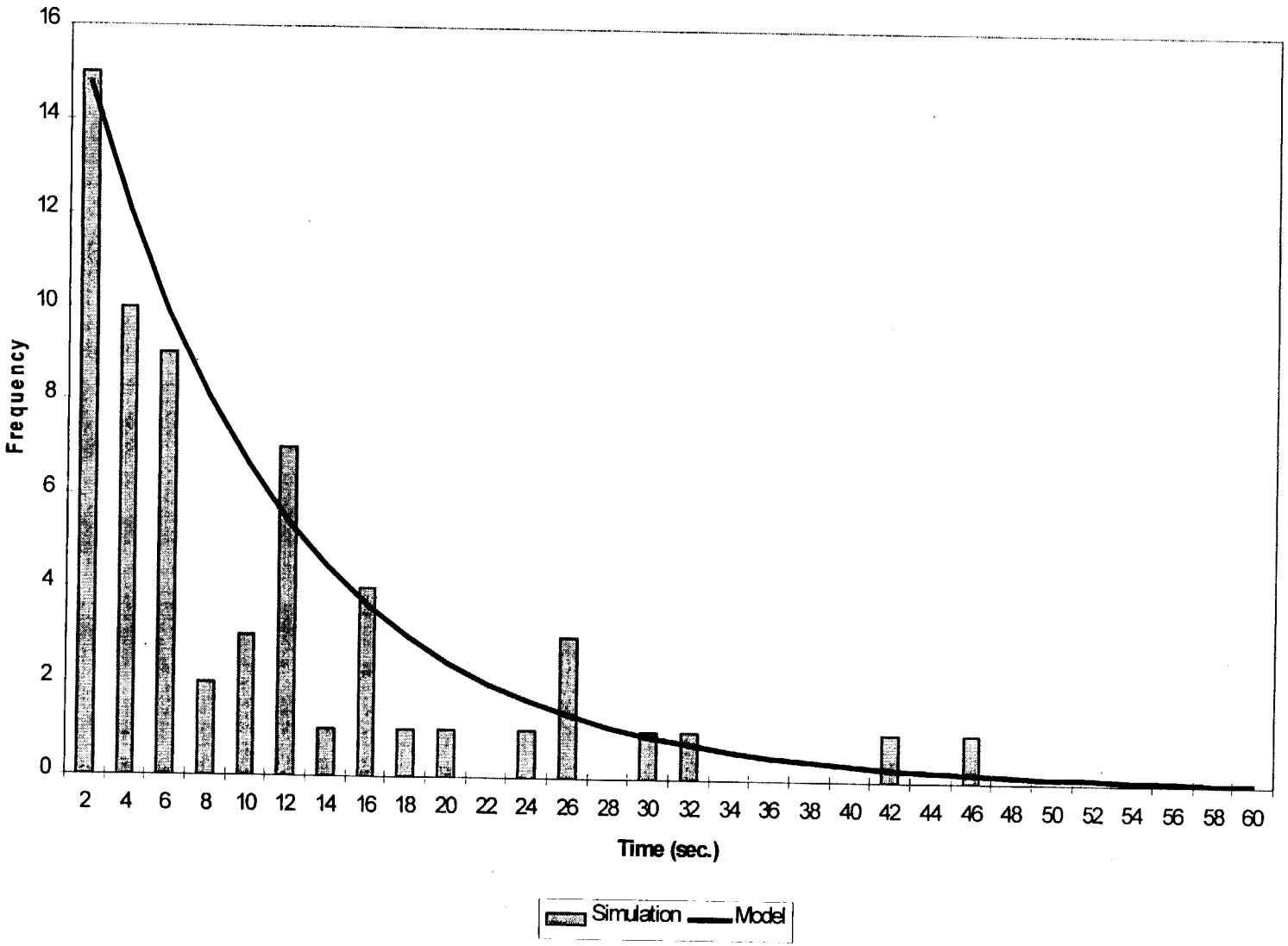
Simulation Verification for Tests Near Fade Event



Simulation Run for TCP Test on a Clear Day



Multiple Simulation Run Results



Conclusions

- BER and error inter-arrival time used for modeling
- NS : modular extendable tool for modeling propagation
- ACTS ns model can be used for research of current and future protocols over similar links

Future Research

- ns in emulation mode
- Mapping of fade data and atmospheric conditions to predict expected Bit Error Rate

Special Thanks

- Kul Bhasin
- Bob Bauer
- Mike Zernic
- Rich Reinhart
- Adesh Singhal
- ACTS Control Room Team at NASA Lewis

SESSION 4. PROPAGATION CAMPAIGN WITH ACTS IN INCLINED ORBIT

Chair: R. Acosta

(NASA/LeRC)

BLUE RIBBON PANEL & I/O OPERATIONS

ROBERT BAUER

ACTS PROPAGATION STUDIES WORKSHOP XI
Oklahoma City, OK
October 23, 1998

SPACE COMMUNICATIONS OFFICE

ACTS INCLINED ORBIT READINESS REVIEWS

- SYSTEM TECHNICAL READINESS REVIEW
  - 6/10/98
  - IN-HOUSE PANEL FROM LEWIS ENGINEERING DIRECTORATE
  - OPERATIONS PLANS AND PROCEDURES
- PROGRAM READINESS REVIEW
  - 8/12/98
  - 8 MEMBER BLUE RIBBON PANEL(BRP) FROM INDUSTRY & GOVT
    - Dr. Leonard Golding, Hughes Network Systems (Chair)
    - Dr. Louis Ippolito - Stanford Telecommunications, Inc.
    - Mr. Brian Abbe - Booz, Allen, Hamilton
    - Ms. Charlene Gilbert, NASA JSC
    - Mr. Frank Dixon, NCS
    - Dr. Al Mac Rae, Mac Rae Technologies
    - Dr. Stephen Goldstein, NSF
    - Dr. Prakash Chitre, Comsat Labs
  - PROGRAM PLANS AND DIRECTION

SPACE COMMUNICATIONS OFFICE

SOMO DIRECTION (ROADMAP)

SOMO(JSC) TASKED WITH:

- LOWERING OF NASA'S OPERTIONS COSTS BY
  - COMMERCIAL ASSET UTILIZATION
    - Space Network (TDRSS); Ground Network (shuttle launch, polar programs); Deep Space Network; NASA Information System Network (NREN, HPCC...); Mission Control Center (Houston)
  - INTEROPERABILITY AND STANDARDIZATION
  - FLIGHT AND GROUND SEGMENT SYSTEM AUTOMATION
  - PROCESS INNOVATION TOOLS
- PROVIDE ENABLING DATA AND MISSION SERVICES TO THE NASA ENTERPRISES
  - HIGH PERFORMANCE COMMUNICATIONS
  - INTELLIGENT SYSTEMS AND AUTONOMY
  - INNOVATIVE MISSION INFORMATION SYSTEMS
- ADVANCE US INDUSTRY LEADERSHIP IN COMMERCIAL SATELLITE COMMUNICATIONS
  - HYBRID NETWORK UBIQUITY
  - PRE-COMPETITIVE RESEARCH AND TECHNOLOGY TO OPEN NEW MARKETS
  - SPACE ENVIRONMENT CHARACTERIZATION

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ACTS DIRECTION

- PROGRAM AND ACTIVITIES MUST BE RELEVANT TO NASA ENTERPRISES AND SOMO ROADMAP
- NEW GOALS DEFINED FOR ACTS IN INCLINED ORBIT. USE ACTS AS A TESTBED TO:
  1. DEMONSTRATE NASA & OTHER GOVERNMENT USES OF TRANSITIONING TO COMMERCIAL SATELLITE SERVICES.
  2. TEST, VERIFY & RESOLVE TECHNICAL ISSUES USING ASYNCHRONOUS TRANSFER MODE (ATM), INTERNET PROTOCOL (IP), OR OTHER PROTOCOLS OVER SATELLITE, INCLUDING INTEROPERABILITY ISSUES WITH TERRESTRIAL NETWORKS.
  3. EVALUATE SPOT BEAM SATELLITE OPERATIONS IN AN INCLINED ORBIT.
  4. VERIFY NEW SATELLITE KA-BAND TECHNOLOGY AND HARDWARE.

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HIGHLIGHTS OF BRP RECOMMENDATION

- CONTINUATION OF THE 2 YR. INCLINED ORBIT OPERATIONS IS MERITED WITH HIGH PAYOFF POTENTIAL
- THREE CLASSES OF EXPERIMENTS
  - PROPAGATION
  - TECHNICAL VERIFICATION
  - APPLICATIONS
- 14 RECOMMENDATIONS
  - 8 CURRENTLY PLANNED
  - 2 NOT CURRENTLY PLANNED, BUT EASILY MET
  - 2 NOT CURRENTLY PLANNED, CHALLENGING TO MEET
  - 2 NOT PLANNED, INFEASIBLE
- STRONG SUPPORT TO CONTINUE PROPAGATION PROGRAM.

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PLAN

MEET RECOMMENDATION AS BEST AS POSSIBLE

BEING PLANNED:
- SITE DIVERSITY
- WET ANTENNA MEASUREMENTS
- COMPARE RESULTS OF PRE-I/O WITH I/O MEASUREMENTS
- TCP/IP AND ATM OVER SATELLITE
- MULTICASTING OVER SATELLITE
- BANDWIDTH ON DEMAND/QUALITY OF SERVICE
- DEMONSTRATIONS
- CASTING STRATEGIC DIRECTION IN TERMS OF NASA, LeRC GOALS

BEING CONSIDERED:
- WIDEBAND MEASUREMENTS
- NGSO/GSO INTERFERENCE MEASURMENTS
- (LIMITED) CONTINUATION OF DATA COLLECTION
- DEPOLARIZATION EFFECTS

NOT CONSIDERED
- SHUTTLE EXPT.
- MEASUREMENTS DURING SUPER-ORBIT

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CONTINUATION OF DATA COLLECTION

- TWO SITES ARE BEING CONSIDERED FOR 1 MORE YEAR OF DATA COLLECTION
- FLORIDA
  - SUBTROPICAL (GLOBAL RAIN CLIMATE ZONE "E")
  - CLOSEST TO MEETING RECOMMENDATION FOR DATA FROM A TROPICAL SITE
- OKLAHOMA
  - MID LATITUDE (GLOBAL RAIN CLIMATE ZONE D2/D1)
  - RECOMMENDED BY PANEL FOR DEPOL MEASUREMENTS
- UNIVERSITY SITES CONSIDERED FOR EASE IN "EXTENDING" THROUGH A GRANT
- MOVE SECOND APT TO SITES FOR DEPOLARIZATION
- MODIFY TERMINALS FOR INCLINED ORBIT OPERATIONS
- *IS THERE INTEREST TO CONTINUE DATA COLLECTION ON A NO-COST BASIS (TO NASA) AT OTHER SITES?*

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ISSUES/CONCERNS/QUESTIONS

- IS THERE VALUE IN COLLECTING PAST 1 MORE YEAR IF 2 FULL YEARS CAN'T BE MET?
- WHAT IS ADDED PRECISION TO DATA BASE BY CONTINUING*?
- WHAT IS THE VALUE OF CONTINUING BEACON MEASUREMENTS AS SPACECRAFT SUPER-ORBITS TO THE HORIZON?
- WHAT DATA IS STILL NEEDED FOR SITE DIVERSITY?
- QUANTIFY HOW ACTS PROPAGATION DATA LOWERS NASA'S OPERATIONS COSTS.
  - IF STATISTICS ARE IMPROVED BY X%, WHAT DOES THAT MEAN TO NASA IN $'S SAVED?
  - CAN DATA BE USED IN DEEP SPACE NETWORK Ka-BAND OPERATIONS TO LOWER COSTS OR IMPROVE OPS?
  - WHAT DOLLAR SAVINGS DOES IMPROVED SYSTEM DESIGN MEAN TO A COMMERCIAL OPERATOR?

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ACTS Propagation Terminals

Tracking ACTS in Inclined Orbit

David B. Westenhaver

Westenhaver Wizard Works, Inc.

746 Lioness Ct SW
Stone Mountain, GA 30087-2855
770-925-1091, wwwinc@crl.com

Presented at ACTS Propagation Studies Workshop XI

Oklahoma City , OK

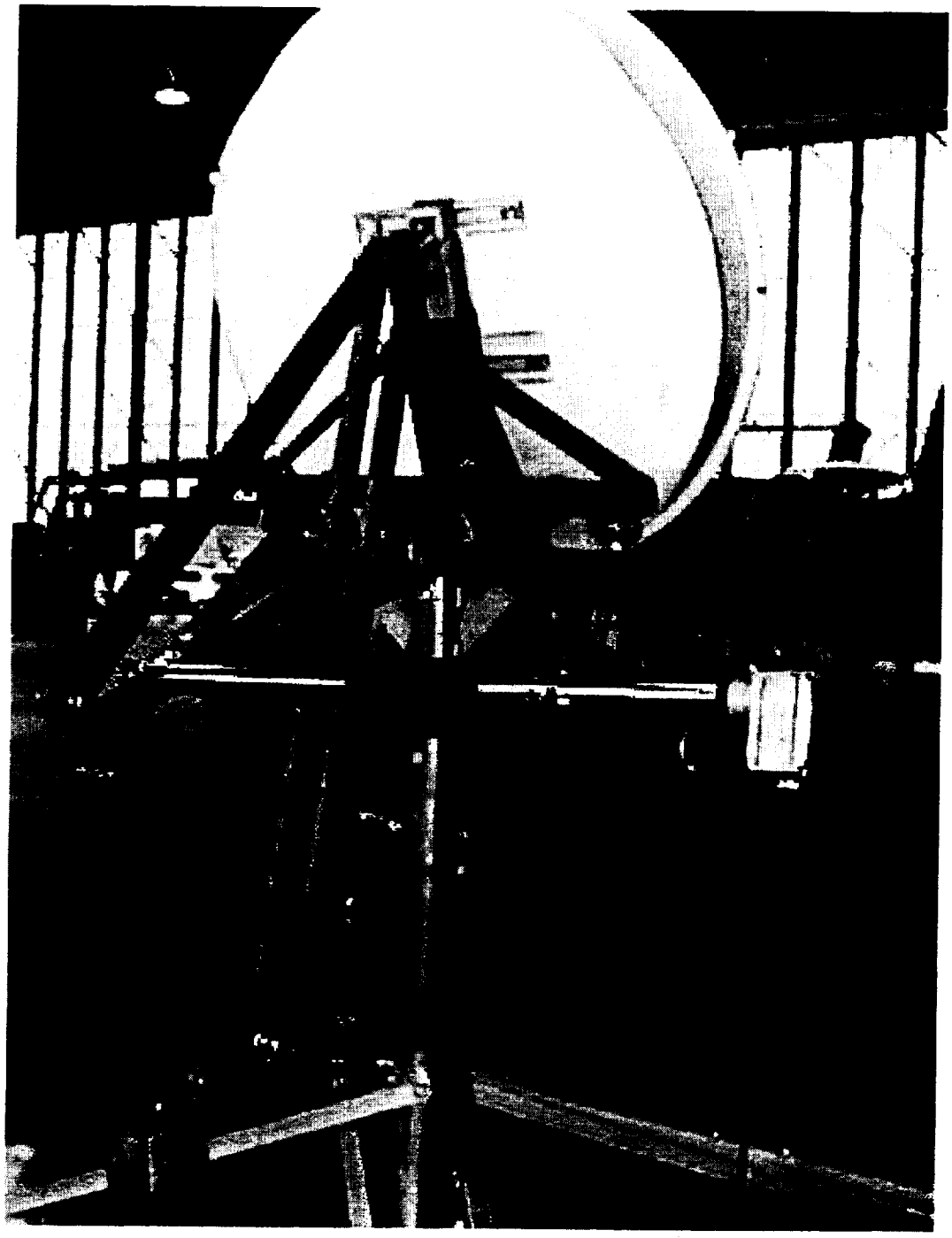
October 23, 1998

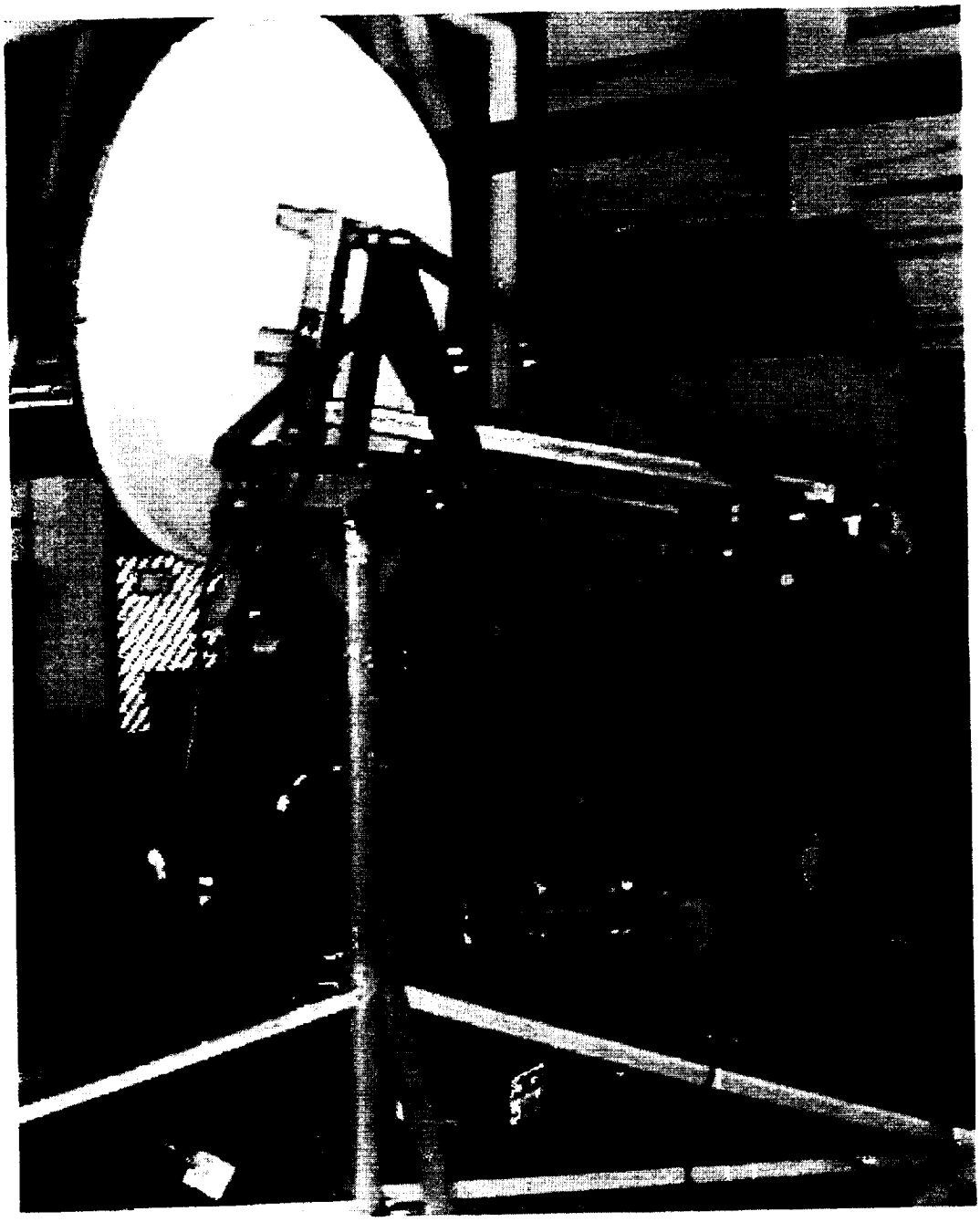
ACTS Propagation Terminals Tracking ACTS in Inclined Orbit requirements.

- The APT tracking is much more stringent than a VSAT system.
- Keep the APT antenna pointed at the ACTS at all times via "Program Tracking".
- All antenna tracking motion to result in less than 0.4 dB signal change with a goal of less than 0.1 dB.
- Antenna mount position and motion time tagged in the raw data files.
- Use "Step-Tracking" peaking algorithm only for "Zeroing" operations.

Mechanical Positioning system requirements.

- Stiff mechanical support.
- Long lever arms for jack screws.
- Motorized jack screws with incremental motor position indicators.
- Limit switches.





Motion Motor Controller requirements:

- Move the mount small angles in a slow controlled predictable manner.
- Accept and perform position commands via RS-232 interface.
- Report selectable and detailed status via RS-232 interface.
- Hold position under wind loading conditions.
- Provide high speed motion for zeroing incremental position counters.
- Retain detailed incremental and initial setup information during power cycling.

Integration with current DACS Collection System requirements.

- Connect Motor controller to DACS at Antenna.
- Add Software to DACS & TSR for the control and motion logging.
- Develop a method to read the ACTS Ephemeris from pointing angle file.
- Retain detailed incremental and initial setup information during power cycling.

Operational Support Issues.

- Develop program to convert ACTS Ephemeris to pointing angle counts for each site.
- Provide the sites with corrected ACTS Ephemeris weekly.
- Keep it working by resolving all antenna pointing issues.

Remove Wet Antenna Surface Effects of Composite Antenna

- The composite antenna's reflecting surface is an aluminum wire mesh imbedded under a plastic textured surface.
- The surface can be re-manufactured to provide a smooth metallic "front surface" reflector.

SESSION 5. PLENARY

Chairs: R. Crane (Univ. of Oklahoma)

D. Rogers (CRC, Canada)

REPORT OF APSW XI PLENARY MEETING

D.V. Rogers and R.K. Crane

At the Eleventh ACTS Propagation Studies Workshop (APSW XI), the ACTS Working Groups held the customary Plenary meeting on 23 October 1998 to address project issues related to experiments being conducted with the NASA ACTS Propagation Terminals (APTs). Results of that meeting are reported here.

I. *ACTS Experimenter Issues and Concerns*

A. *Data Collection/Quality*

During the meeting, NASA LeRC announced that, consistent with recommendations of the Blue Ribbon Panel, measurements are planned to be continued during the next calendar year in the inclined-orbit mode, but at only two of the ACTS Propagation Terminal (APT) sites, Oklahoma and Florida. The new configuration will deploy two existing APTs at each of these sites to permit site diversity measurements. Consideration will also be given to incorporating the capability to collect path depolarization data at these two sites.

The APTs to be used during the inclined-orbit phase of ACTS operations will have to be adapted with satellite tracking capability. A tracker designed for this purpose was illustrated during the presentation by NASA LeRC (R. Bauer). A method to minimize the antenna wetting effects for the APTs was also presented by D. Westenhaver. The approach is to machine the dielectric surface to the level of the embedded wire-reflecting surface, and to paint the new surface with conductive paint. Presumably, a shield or blower would also be installed to keep the antenna feed window dry.

The new configuration will require redeployment of two of the seven terminals. NASA also plans to locate another terminal at the site-support contractor's facility to serve for spare parts, so that five of the existing APTs are then obligated under the official NASA measurements program. New Mexico (S. Horan) offered to upgrade, at no cost to NASA, their APT, assuming that the APT can be removed from the current location at White Sands. Colorado (J. Beaver) expressed some interest in retaining an APT as well. Deployment per this arrangement would utilize all seven of the APTs.

Experimenters interested in continuing measurements with upgraded APTs were requested to inform R. Bauer of NASA LeRC promptly. However, it was made clear by NASA LeRC (R. Acosta) that if existing APTs are needed for redeployment in the new measurement configuration, they will be recalled.

With incorporation of an antenna tracking capability, ACTS measurements with the APTs should be feasible until the planned deorbit of the satellite in September 2000.

Mention was also made of the requirement to have all ACTS preprocessed data for calendar year 1998 delivered to the ACTS Data Center by March 1999.

ACTIONS:

Experimenters should inform NASA LeRC (R. Bauer) of any interest in upgrading and retaining an ACTS Propagation Terminal for inclined-orbit operations. All experimenters should also be aware of the need to complete delivery of all preprocessed data through December 1998 by March 1999.

B. *Reporting of ACTS Data and Results*

Development and reporting of results and propagation models within the ACTS project was discussed. A general proposal was made that another special issue be planned much like the June 1997 *Proceedings of the IEEE* Special Issue on "Ka-band Propagation Effects on Earth-Satellite Links." N. Golshan, R. Acosta and D. Rogers were proposed as guest editors. Support was expressed to approach the IEEE to determine if another special issue of *Proc. IEEE* is possible for reporting of the ACTS results.

During the discussion, various subject areas and coordinators were identified for inclusion in a special issue as follows:

- signal scintillation - C. Mayer;
- ACTS system overview - D. Westenhaver
- summary of basic ACTS propagation statistics - R. Crane;
- antenna-wetting model/experimental verification - R. Crane
- radar issues - J. Beaver;
- fade durations - H. Helmken;
- fade slopes - J. Pinder;
- fade mitigation - R. Acosta;
- site diversity - H. Helmken;
- cloud effects - C. Mayer.

ACTION:

N. Golshan will approach the IEEE to determine if a special issue of *Proc. IEEE* is possible and what the corresponding schedule will be.

II. *Other Topics*

During the Plenary, a wide-ranging discussion was pursued on future needs for propagation data. Propagation information for the Q/V-bands, which feature 3 GHz of spectrum (37.5 - 40.5 GHz downlink, 47.2 - 50.2 GHz uplink) allocated in each direction for earth-space services, was noted as a prime area requiring study and preferably measurements. J. Goldhirsh pointed out the need to validate nongeostationary orbit (NGSO) and Low Earth Orbit (LEO) link calculations with measurement data. S.

Horan noted that these two requirements might be met by flying a Q/V-band beacon package on the Space Station for a year or two. R. Bauer reported that there is indeed interest in using the Space Station for scientific projects of this nature.

L. Ippolito remarked that the Iridium system has already deployed about 60 satellites in orbit, each with a 20-GHz beacon, which could be used to study LEO propagation characteristics. He suggested that NASA might want to contact Motorola about this possibility. R. Crane concurred that the LEO prediction problems may be important.

N. Golshan stated that for NASA to fund any endeavor, it would have to relate to NASA's requirements (e.g., work related to LEO issues would need to address the interests of Goddard Space Flight Center) or to NASA enterprises. R. Bauer remarked that NASA has prime interests in the 40/50-GHz band and the bands above 71 GHz (precompetitive technology). L. Ippolito stated that the NAPEX group should try to determine what information is needed at Q/V band. A. Dissanayake recalled that a 40/50-GHz satellite system had been mentioned at the previous NAPEX meeting in Austin, and that it might be usable for some of the requirements.

N. Golshan noted that optical communication issues are also important to NASA (due to the ability to focus the beam). Prime propagation concerns arise related to signal scintillations, cloud effects, etc. Wideband transmission at gigabit rates is also of interest, and might be achieved by using earth terminals situated in desert locations, perhaps with site diversity, etc. He also remarked that NASA's Deep Space Network typically uses 5° - 10° as the lowest operating angle.

R. Bauer stated that NASA hasn't done a good job of explaining its new requirements per the new "roadmap" (mainly because the shift was so sudden), and that perhaps NASA/JPL and LeRC can collaborate to get this information to the propagation community.

ACTION:

R. Bauer, R. Acosta and N. Golshan will collaborate to explain the future requirements of the new NASA "roadmap," and try to identify sources of funding for future needs.

III. *Next Meeting*

The group tentatively agreed to hold the next NASA Propagation Experimenters Meeting in Herndon, Virginia, during 3-4 June 1999. It is hoped that this venue will promote involvement by NASA/GSFC personnel.

IV. *Information*

E. Smith (U. Colorado) reported that U.S. ITU-R Study Group 3 (Radiowave Propagation), Chaired by Eldon Haakinson of NTIA/ITS, is scheduled to meet Wednesday, January 6, 1999, from 0900-1100 in the Engineering Center at the University of Colorado, Boulder, during the URSI National Radio Science Meeting.

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Acronyms

ACA	attenuation with respect to clean air (or clear air)
ACS	Advanced Communications Systems (in Stanford Telecommunications, Inc.)
ACKS	acknowledgements
ACTS	Advanced Communications Technology Satellite
ACTSPP	Advanced Communications Technology Satellite (ACTS) preprocessing program (translates raw beacon data)
AFS	attenuation with respect to free space
AGA	attenuation due to gaseous absorption
APL	Applied Physics Laboratory
APSW	Advanced Communications Technology Satellite (ACTS) Propagation Studies Workshop
APT	ACTS Propagation Terminal (at Colorado State University)
ARD	radiometrically derived attenuation
ARS	statistical attenuation ratio
ATM	asynchronous transfer mode
BER	bit error rate
CCIR	(now changed to ITU-R—International Telecommunications Union-Radio
CDF	cumulative distribution functions
CHILL	University of Chicago and Illinois Water Survey (radar)
CMU	Carnegie Mellon University
COAG	group of surface weather stations in Colorado
COAGMET	group of surface weather stations in Colorado (same as COAG)
COMSTAR	(communications satellite)
CONSTMM	calibration constant for successive months
CRG	capacitive rain gauge
CSU	Colorado State University
DAH	Dissanayake, Allnutt, and Haidara (rain attenuation model, also called the USA model)
DRX	data receiving (collection)
Eb/No	energy per bit by noise density ratio
ExCell	exponential cell (model)
FEC	forward error correcting
FTS	field test site
GBS	Global Broadcast System
GPS	Global Positioning System
HDR	high data rate
IEEE	The Institute of Electrical and Electronics Engineers, Inc.
INMARSAT	International Maritime Satellite
IP	internet protocol
ITU-R	ITU-R: International Telecommunications Union—Radiocommunications
JHU	Johns Hopkins University

Kdp	specific differential phase
LBNL	Lawrence Berkeley National Laboratory
Ldr	linear depolarization ratio
LEO	low earth orbit
LET	Link Evaluation Terminal
LMSS	Land Mobile Satellite System
LeRC	Lewis Research Center (Cleveland, OH)
MARECS-B2	(International Marine Satellite Consortium satellite)
m.a.s.l.	meters above sea level
Mesonet	mesoscale meteorological network of Oklahoma
MPM	Microwave Propagation Model (Basically Liebe's Atmospheric Model)
NCDC	National Climatological Data Center
NOAA	National Oceanographic and Atmospheric Administration
NS	Network Simulator
OU	Oklahoma University (Norman, OK)
PARC	Palo Alto Research Center
PDF	probability density function
R-H	Rice-Holmberg (rain model)
RHI	Range Height Indicator
RHV (%) -	cross correlation coefficient
RMS	root mean square
Satcom	satellite communications
SCTC	Space Communications Technology Center
STel	Stanford Telecomunications, Inc., Reston, VA
TBG	tipping bucket gauge
TBRG	tipping bucket rain gauge
T-C	two component (model)
TCP	Transmission Control Protocol
TDRSS	Telecommunications and Data Relay Satellite System
TEC	total electron content
TSR	transmit & stay resident
UAF	University of Alaska, Fairbanks
UBC	University of British Columbia
UCB	University of California at Berkeley
URSI	The International Union of Radio Science
USAT	ultrasmall aperture terminal (transportable 36-cm) station
USC/ISI	University of Southern California's Information Sciences Institute
UTC	universal time coordinates (Greenwich mean time)

VSAT	very small aperture terminal
wrt	with respect to
WWV	plugin card in the ACTS propagation terminal's collection PC, which is used to receive the standard time from Colorado and adjust the PC clock accordingly
XPD	Cross-polarization discrimination
Zdr	differential reflectivity
Zhh	horizontal reflectivity

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The Advanced Communications Technology Satellite Propagation Studies Workshop (APSW) is convened each year to present the results of the Advanced Communications Technology Satellite (ACTS) Ka-band propagation campaign. Representatives from the space community including industry, academia, and government who are interested in radiowave propagation at Ka-band are invited to APSW for discussions and exchange of information. The ACTS Propagation campaign will complete five years of Ka-Band data collection at seven sites in North America by December 31, 1998. Through this effort, NASA is making a major contribution to the effective utilization of this band by providing timely propagation data and models for predicting the performance of Ka-band links between space and ground.

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